Establishment of a GPS High Accuracy Geodetic Network in Romania

Tomás Soler and Lucy W. Hall

ABSTRACT: The National Oceanic and Atmospheric Administration (NOAA) signed an interagency agreement with the U. S. Agency for International Development (AID) to impart technical advice and assistance to the Romanian government for upgrading their national first-order geodetic network. NOAA's National Geodetic Survey (NGS), which has been using the global positioning system (GPS) for geodetic applications since its inception, was assigned the task of helping various Romanian mapping and cartographic organizations. The challenge: to define an accurate spatial framework facilitating the future implementation of geographic information systems (GIS) in the country and to formulate the fundamental geodetic coordinate system to which all divestiture of state-owned farms could be progressively and uniformly referenced. This article concentrates on the description of the methodology followed to reach this geodetic goal and presents the results derived to define a set of geocentric coordinates which are consistent with the European Geodetic Reference System (EUREF89) used in all continental European geodetic operations.

Introduction

Recent vigorous democratic changes in the political configuration of many central and eastern European regimes have increased the need for the introduction of new policies focussing on a more efficient utilization of rural land. Privatization of government parcels of land is seen as a first step toward a market-oriented infrastructure where individual initiative would lead to a smooth transition, encouraging free enterprise as the primary avenue for stimulating rapid growth and economic progress.

The involvement of NOAA's National Geodetic Survey (NGS) in this ambitious development program was purely technical and encompassed three distinct obligations (Challstrom 1995):

- to instruct Romanian government engineers in up-to-date GPS survey technology;
- to procure for the Romanian government state-of-the-art GPS equipment capable of making high-accuracy observations; and
- using this equipment, to observe and determine coordinates of a fundamental network of seven points referred to a rigorously defined geocentric reference frame which would be central to future transfer of information to a totally digitized cartographic data base.

From this primary geodetic framework, Romanian professionals (government and private) plan to add supplemental GPS points at intervals of about 40-km spacing and, by incorporating kinematic GPS methods, photogrammetry, and/or classical "total station" techniques, to establish a cadastral procedure capable of identifying and measuring every land parcel in the country.

The project was coordinated with the Romania Ministerul Agriculturii si Alimentatiei (MAA), the Institutul de Geodezie, Fotogrammetrie, Cartografie si Organizarea Teritoriului (IGFCOT), and the Directia Topografica Militara (DTM). Besides NGS personnel, two experts familiar with the U.S. Public Land Survey System from the U.S. Bureau of Land Management (BLM) and a technical representative from Trimble Navigation were also involved in the Romanian campaign. Credit for this endeavor and its final achievements must be shared with the diverse Romanian staff, in particular, the members of IGFCOT who well deserve recognition for their valuable participation. More information on their responsibilities is given in Benea and Buse (1995) and Buse and Benea (1995).

Terrestrial Coordinate Systems

It is well-known that the coordinate system to which the components of the reduced GPS vectors refer is the one implied by the orbital ephemerides utilized. GPS users have two alternatives: broadcast

Tomás Soler is Chief of the Global Positioning System (GPS) Branch and **Lucy W. Hall** is a geodesist with the National Geodetic Survey, NOS, NOAA, 1315 East-West Highway, Silver Spring, MD 20910.

Surveying and Land Information Systems, Vol. 55, No. 4, 1995, pp. 183-191

or precise ephemerides. Broadcast ephemerides are predicted and, therefore, they are less accurate (by about 4 m) than their precise counterpart. However, they are available on a real-time basis through the message continuously transmitted by the satellites. In contrast, precise ephemerides are determined after the fact using actual GPS observations collected by an independent world-wide network of GPS tracking stations and currently are considered accurate to a few decimeters.

In order to process the raw GPS data collected in Romania, all GPS reductions were performed using precise orbits given in the so-called International Earth Rotation Service (IERS) Terrestrial Reference Frame of 1992 (ITRF92). As will be discussed later, the exact epoch chosen for all processing was the average epoch of the observational period, namely, 1994.7.

ITRF92 was considered the best available conventional terrestrial frame at the time that the processing was done. It belongs to the well-known ITRF series which was created under international sponsorship in order to satisfy the accuracy requirements of various modern space techniques (Feissel and Gambis 1993). The origin, coordinate axes orientation, and scale of the ITRF frames are implicitly defined by the coordinates adopted for the terrestrial sites of each global solution. It is generally assumed to be geocentric with a maximum uncertainty of ± 5 cm. The so-called IERS Reference Pole (IRP) and IERS Reference Meridian (IRM) are consistent with the corresponding directions of the old BIH Terrestrial System (BTS) within ± 0.005″.

In the meantime, a new ITRF93 frame whose orientation and rate of change with time was constrained to be consistent with the IERS series of Earth Orientation Parameters (EOP) was released (Boucher et al. 1994). The scale and origin of every ITRF frame is defined by holding to zero the three translations and scale factor of the satellite laser ranging (SLR) solutions. These are dynamic solutions fundamentally based on the motion of Lageos around the Earth's center of mass. The orientation of the coordinate axes is constrained by the directions of extragalactic sources determined by radioastronomy methods: specifically, very long baseline interferometry (VLBI).

Associated with ITRF92 (or ITRF93) there is also defined a velocity field. That is, each station has a velocity vector indicating the displacement in time due to the motion of the tectonic plate on which the point is located. These rotations can be approximated by geophysical models such as NUVEL NNR-1 (McCarthy 1992, 21).

Three European permanent GPS tracking stations of the International GPS Service for Geodynamics (IGS) world-wide network, whose positions are well known in the ITRF92 coordinate system, were selected as fiducial points. In turn, their coordinates were assumed to be "true" and their values fixed in the first phase of GPS processing. The main reason for selecting three fiducials was to average unknown errors, if any, in the position of the IGS stations which, obviously, will impact any set of derived coordinates. The three designated fiducial stations are MADRID (Spain), ONSALA (Sweden), and WETTZELL (Germany).

The selection of these three stations was primarily based on their proximity to accurately determined VLBI points and on their long and reliable history of GPS performance.

All Cartesian coordinates of the IGS fiducial stations were available in the ITRF92, epoch 1994.0, reference frame as disseminated by IERS (Altamimi and Boucher 1993). These values were transformed to epoch 1994.7 using the IERS velocity field before processing started. With the coordinates of these three stations fixed as input, the coordinates of a single station located in the capital of Romania, Bucharest, were determined.

Data Collection and Processing

The field data of the Romanian GPS survey comprised a total of four days of observations collected using dual frequency Trimble 4000SSE instruments during September 26-29, 1994 (day of year = doy # 269, 270, 271, and 272). Observations started at 0900 UTC on September 26 and continued uninterrupted during four consecutive 24-hour sessions. Details concerning the planning, preparation, reconnaissance, actual observational logistics, and other related activities are in Leigh and Smith (1995).

A total of seven stations (CONSTANTA, DEALUL PISCULUI, MOSNITA, OSORHEI, SFÎNTU GHEORGHE, SIRCA, and STANCULESTI) were surveyed in Romania using GPS methods. The requirements of the project specified NGS A-order relative accuracy standards (i.e., 5 mm + 1:10,000,000 (Federal Geodetic Control Committee 1988)). All of these stations were existing first-order horizontal geodetic control points and were uniformly distributed throughout the country. The station in Bucharest (DEALUL PISCULUI, hereafter referred to as PISCULUI) was located at the Military Astronomic Observatory and for processing purposes was considered the origin and primary point of the whole GPS Romanian network.

Observations of weather data at or about antenna height were recorded at all locations at the beginning of each session and at intervals of four hours thereafter. A Belfort Psychro-dyne psychrometer was used to determine relative humidity. A Pretel Model

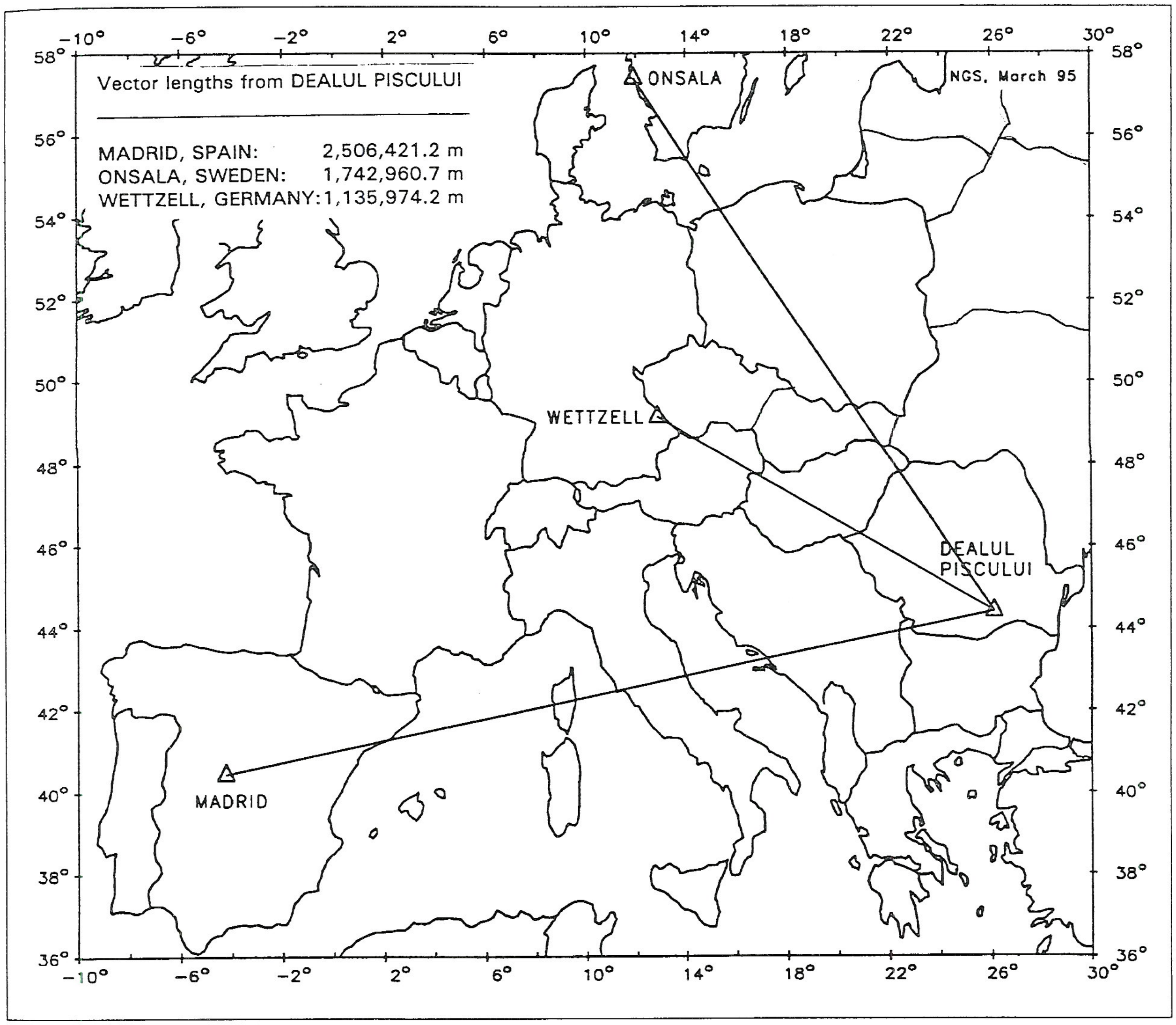


Figure 1. Vectors from three IGS stations used to determine the coordinates of DEALUL PISCULUI in Bucharest.

K2 Altimeter/Barometer was used to obtain the barometric pressure. Weather during the observation period was exceptionally good and without incident. Average daily temperatures ranged between 15.4 and 24.9 degrees Celsius.

Four independent sessions of 24 hours each (beginning at 0900 UTC one day and ending at 0900 UTC the next day) were processed at NGS headquarters in Silver Spring, Maryland, using a recently developed program named PAGE4 (Schenewerk 1993) which is adapted for UNIX-type HP 9000/700 series workstations. PAGE4 is a new generation of multi-tasking programs used to process GPS data in the static mode which has replaced OMNI, the original NGS vector processor software. Included among the improvements recently incorporated are: generation of an optimal satellite reference scenario; better ability to detect cycle slips; better outlier detection and automatic removal routines; application of antenna /elevation-dependent phase corrections—a must when different types of antennas are combined; and the capability to solve for tropospheric biases at any arbitrary epoch, instead of once per session as OMNI currently does. In summary, new consolidated advantages are: improved math models, flexible strategies for estimating unknowns, and, if desired, the possibility of performing hands-off (batch) processing of sessions lasting several days.

All 25 satellites in the present GPS constellation were used in the reductions of each individual day. At any given time a minimum of four and a maximum of nine satellites were simultaneously visible above the horizon. Although data were collected at 15-second intervals, the selected sampling rate to reduce the observations of this project was set at 30 seconds, a restriction imposed by the data collection interval at the IGS stations. A minimum elevation angle of 20° was chosen as the cut-off angle for

Session	x		y		z	
	4,098,299 m +		**2,008,691 m +**		**4,440,543 m +**	
1	0.944 m	(-1 mm)	0.120 m	(-3 mm)	0.602 m	(-1 mm)
2	0.943 m	(-2 mm)	0.127 m	(4 mm)	0.603 m	(0 mm)
3	0.946 m	(1 mm)	0.120 m	(-3 mm)	0.604 m	(1 mm)
4	0.948 m	(3 mm)	0.125 m	(2 mm)	0.603 m	(0 mm)
mean	0.945 m ± 3 mm		0.123 m ± 3 mm		0.603 m ± 1 mm	

Table 1. Repeatability of coordinates [ITRF92, epoch 1994.7] at DEALUL PISCULUI. Shown in parentheses are the differences of each component with respect to its mean.

all carrier phase observables during the processing stage. Nevertheless, elevation masks were generally set to zero degrees during field observations.

Precise post-fitted ephemerides generated by the Center for Orbit Determination in Europe (CODE) located at the Astronomical Institute, University of Bern, were employed in all reductions. These are three-day orbital solutions which at the time of the observations referred to ITRF92, epoch 1994.0 (at the time of writing, to ITRF93, epoch 1995.0), and is the ephemeris recommended for precise geodetic positioning in Europe by the Technical Working Group overseeing the European Geodetic Reference System (EUREF). Notice that the values of the coordinates of the three fiducial stations used in the reductions described here are consistent with the frame and epoch of the precise satellite ephemerides employed. However, because observations were collected at the end of September 1994, before starting vector processing with PAGE4, the original coordinates of the IGS fiducial stations available at epoch 1994.0 were rotated to epoch 1994.7. As described before, this was accomplished by applying the plate rotations according to the velocity field published by IERS. As a result of this precaution, the final coordinates of every determined station would refer also to ITRF92 and epoch 1994.7.

Only static multi-station relative GPS procedures between selected "base" and "remote" stations were implemented. After all nonautomatically corrected data outliers and cycle slips (on frequencies L1 and L2), if any, were manually cleaned (relying as reference on postfitted residual plots), final solutions were determined using double-difference, carrier phase measurements, and the ionosphere-free linear combination of L1 and L2 model (Leick 1995, 306). A zenith tropospheric scale factor was solved every three hours. Considering the length of vectors involved, no attempt was made to fix ambiguity biases.

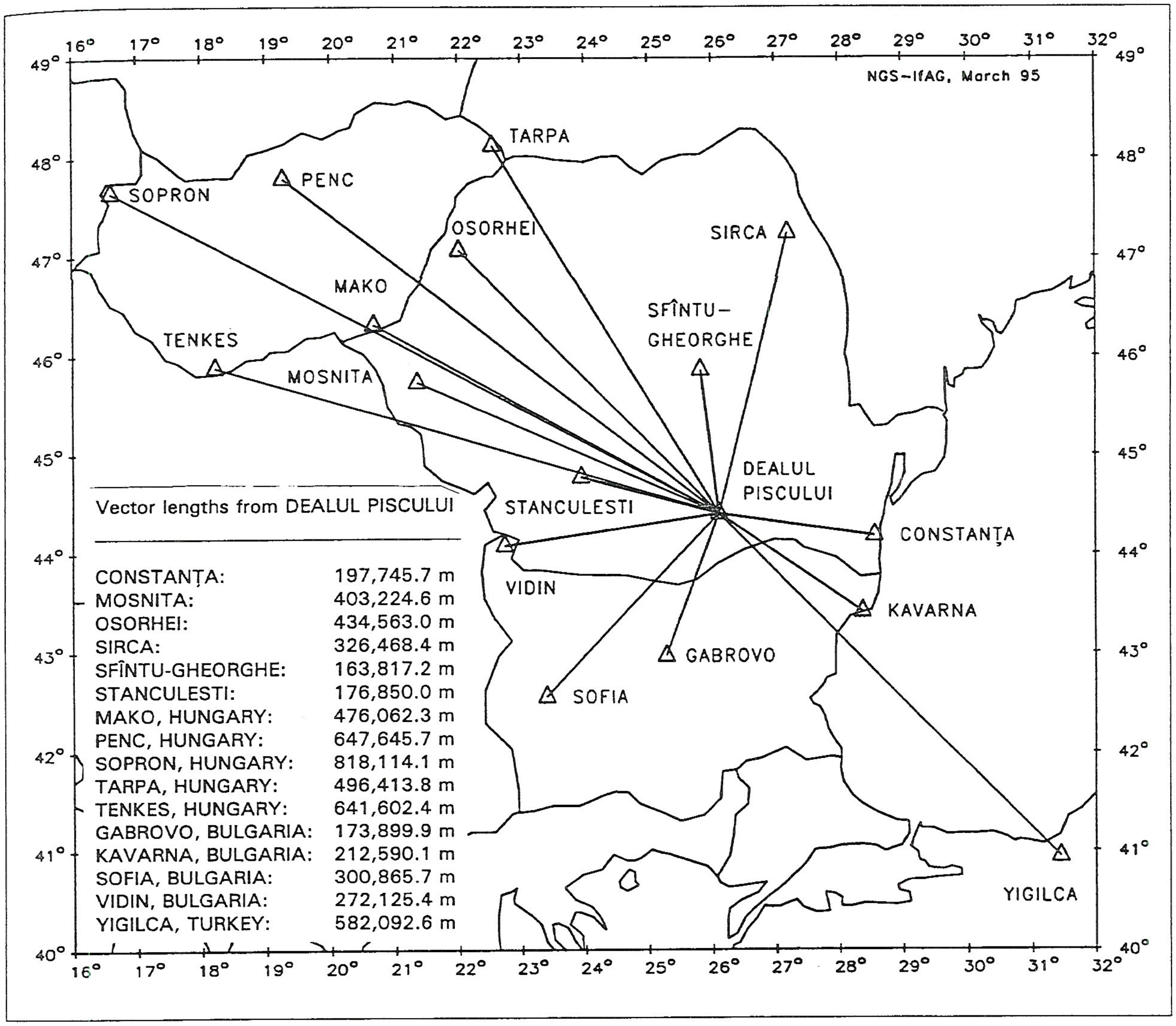
Results Referred to ITRF92

As an initial stage of the reduction process, the coordinates of PISCULUI were determined using the three vectors from the IGS fiducial stations, namely, MADRID, ONSALA, and WETTZELL (see Figure 1). Four sessions of 24 hours each produced a set of 12 components for the "remote" station at PISCULUI. The individual results are presented in Table 1.

It is evident from the tabulated values that the repeatability of the computations greatly exceeds the requirements of the project. The maximum relative error in any of the components with respect to its average value is only 1.5×10^{-9} (1.5 parts per billion (ppb)), an agreement difficult to imagine before the improved GPS observational and reduction methods became available.

The average value of these four determinations was accepted as the final set of coordinates in the ITRF92, epoch 1994.7 for station PISCULUI, which subsequently assumed the role of "base" (reference) point for the rest of the network. Afterwards, a strictly radial network propagating from Bucharest was executed to obtain, relative to PISCULUI, the coordinates of the remaining six stations in Romania.

Through cooperation with the Institut für Angewandte Geodäsie (IfAG) in Frankfurt, Germany, GPS data for other European geodetic stations were also obtained. Five of these stations were in Hungary (MAKO, PENC, SOPRON, TARPA, and TENKES); four in Bulgaria (GABROWO, KAVARNA, SOFIA, and VIDIN); and one in Turkey (YIGILCA). All of these stations were occupied simultaneously with the seven Romanian points and the data and observational logs exchanged between NGS and IfAG (Marjanovic et al. 1995). Three of the stations located in Hungary are part of the Hungarian Geodynamic GPS Reference Network (HGRN) which was deployed to study geodynamic activity in the region (Fejes et al. 1993). Some recent revisions and updates were presented in (Fejes et al. 1994; Ádám et al. 1994), where the geodynamic network is expanded to include most of Central Europe, including Romania. Activities relating to the GPS geodetic program in Bulgaria were reported in Milev et al. 1994. For completeness and to simplify the work involved, it was decided to determine from PISCULUI (see Figure 2) the positions of all available stations, although, if necessary, the components of any vector



Vector lengths from DEALUL PISCULUI	
CONSTANŢA:	197,745.7 m
MOSNITA:	403,224.6 m
OSORHEI:	434,563.0 m
SIRCA:	326,468.4 m
SFÎNTU-GHEORGHE:	163,817.2 m
STANCULESTI:	176,850.0 m
MAKO, HUNGARY:	476,062.3 m
PENC, HUNGARY:	647,645.7 m
SOPRON, HUNGARY:	818,114.1 m
TARPA, HUNGARY:	496,413.8 m
TENKES, HUNGARY:	641,602.4 m
GABROVO, BULGARIA:	173,899.9 m
KAVARNA, BULGARIA:	212,590.1 m
SOFIA, BULGARIA:	300,865.7 m
VIDIN, BULGARIA:	272,125.4 m
YIGILCA, TURKEY:	582,092.6 m

Figure 2. Vectors used from DEALUL PISCULUI in Bucharest to determine the coordinates of the rest of the stations.

between stations at epoch 1994.7 could be derived and used, i.e., for strain analyses in crustal motion studies.

Because the coordinates of every other station were determined relative to PISCULUI following a two-step process (i.e., fiducials → PISCULUI → network stations), a simple experiment was designed to check the validity of the results. Implementing an approach similar to the computation of the coordinates of the primary station in Bucharest, the coordinates of station MOSNITA were independently obtained using the three original IGS fiducials (i.e., fiducials → MOSNITA). The discrepancies between the values given in Table 2 (from PISCULUI), and the direct technique (from the three fiducials) were only 1 mm, 3 mm, and 3 mm, respectively, along the *x*, *y*, and *z* components. This remarkable agreement shows that the approach followed here, as expected, is equivalent (only millimeter differences were encountered) to the individual determination of the position of each station from the three fiducial stations. This partial investigation also corroborated an error detected in the recording of the antenna height at MOSNITA due to a change of receiver at this station during the last two days of the campaign. As a consequence, two vectors (doy #271 and 272) from PISCULUI to MOSNITA were rejected in the final analysis.

A minimally constrained network adjustment using NGS program LAP (a version of ADJUST restricted to GPS vectors) with station PISCULUI held fixed to the computed coordinates in the ITRF92, epoch 1994.7 from Table 1, was performed. The adjustment "a posteriori" standard deviation of unit weight was 6.5. Although this value may appear too large, it is in agreement with the order of magnitude expected for projects with these characteristics and the over-optimistic standard deviations for the phase observables implicitly assumed by program PAGE4.

	x	y	z	σ_e	σ_n	σ_u
	(m)	(m)	(m)	(mm)		
CONSTANTA	4023362.141	2190844.209	4422995.386	2	3	5
DEALUL PISCULUI	4098299.945	2008691.123	4440543.603	2	1	4
MOSNITA	4153382.448	1623173.008	4545098.718	1	1	4
OSORHEI	4034633.439	1631849.587	4647381.793	3	1	9
SIRCA	3858208.752	1983192.069	4660288.107	4	1	6
SFÎNTU-GHEORGHE	4005316.858	1937791.933	4555276.054	2	2	6
STANCULESTI	4145351.417	1840743.984	4469798.317	3	2	7
MAKO, Hungary	4128720.567	1557707.422	4589954.386	4	2	6
PENC, Hungary	4052449.691	1417680.980	4701407.047	5	2	6
SOPRON, Hungary	4125618.935	1230226.011	4690656.269	2	1	12
TARPA, Hungary	3939065.750	1635574.735	4726647.262	3	3	11
TENKES, Hungary	4224902.687	1390480.307	4556477.745	4	3	15
GABROVO, Bulgaria	4227589.937	1996278.317	4324909.660	2	2	9
KAVARNA, Bulgaria	4083131.497	2205288.853	4361084.285	1	2	11
SOFIA, Bulgaria	4319372.301	1868687.623	4292063.880	5	1	10
VIDIN, Bulgaria	4233068.538	1773729.993	4414410.511	2	2	7
YIGILCA, Turkey	4117361.885	2517076.968	4157679.174	3	1	9

Table 2. Preliminary station Cartesian coordinates [ITRF92, epoch 1994.7]. (Formal errors are given along the local east, north, and up frame.)

Figures 3 and 4 depict all adjustment residuals (one per station per day) projected on the planes of the geodetic horizon (east versus north) and geodetic meridian (east versus ellipsoidal height = up). The GRS80 ellipsoid was used for these calculations. The plots in the figures present each observation residual as obtained from the least-squares radial network adjustment. Notice, for example, that the horizontal displacement does not exceed, respectively, ±0.6 cm and ±1.0 cm in latitude and longitude. However, the RMS of the scatter are only 3 mm and 2 mm in longitude and latitude, respectively. The larger error in longitude arises from model errors related to timing, which are reflected in longitude due to the rotation of the earth and the peculiar satellite ground-track coverage. Higher vertical uncertainties are consistent with the difficulty in modeling the atmospheric refraction (ionosphere and troposphere). The magnitude of the vertical and horizontal errors are not necessarily correlated, although a systematic degradation in the sense latitude, longitude, and height, has been well known since the introduction of GPS to geodetic operations (see, for example, Soler et al. 1991).

The preliminary set of coordinates of all stations as processed at NGS according to the procedures just described and referred to the ITRF92, epoch 1994.7, is given in Table 2. Formal errors of each Cartesian coordinate are transformed to a local geodetic coordinate system which is more intuitive and easier to visualize. However, small undetected systematic biases may still be present in the reductions and the values of the formal errors should not be taken in an absolute sense. Investigations are underway to account for any possible unmodeled systematic effects (atmospheric refraction, incompatibility of antenna phase centers, etc.) in order to ascertain the final accuracy of the coordinates. It is estimated that, after a rigorous analysis has been completed, the tabulated preliminary coordinates could not change, if at all, by more than 1 cm in latitude and longitude and about three times that amount in ellipsoid height.

Results Referred to EUREF89

The necessity of establishing a unique reference system in continental Europe, to which all modern mapping and cartographic digital data bases could refer, prompted several years ago the decision to define and materialize a new European Geodetic Reference System (EUREF) (Seeger 1994; Seeger et al. 1995). The stations defining the frame in question referred to as the European Terrestrial Reference Frame of 1989 (ETRF89), are a subset of the IERS ITRF89. The EUREF Technical Working Group has

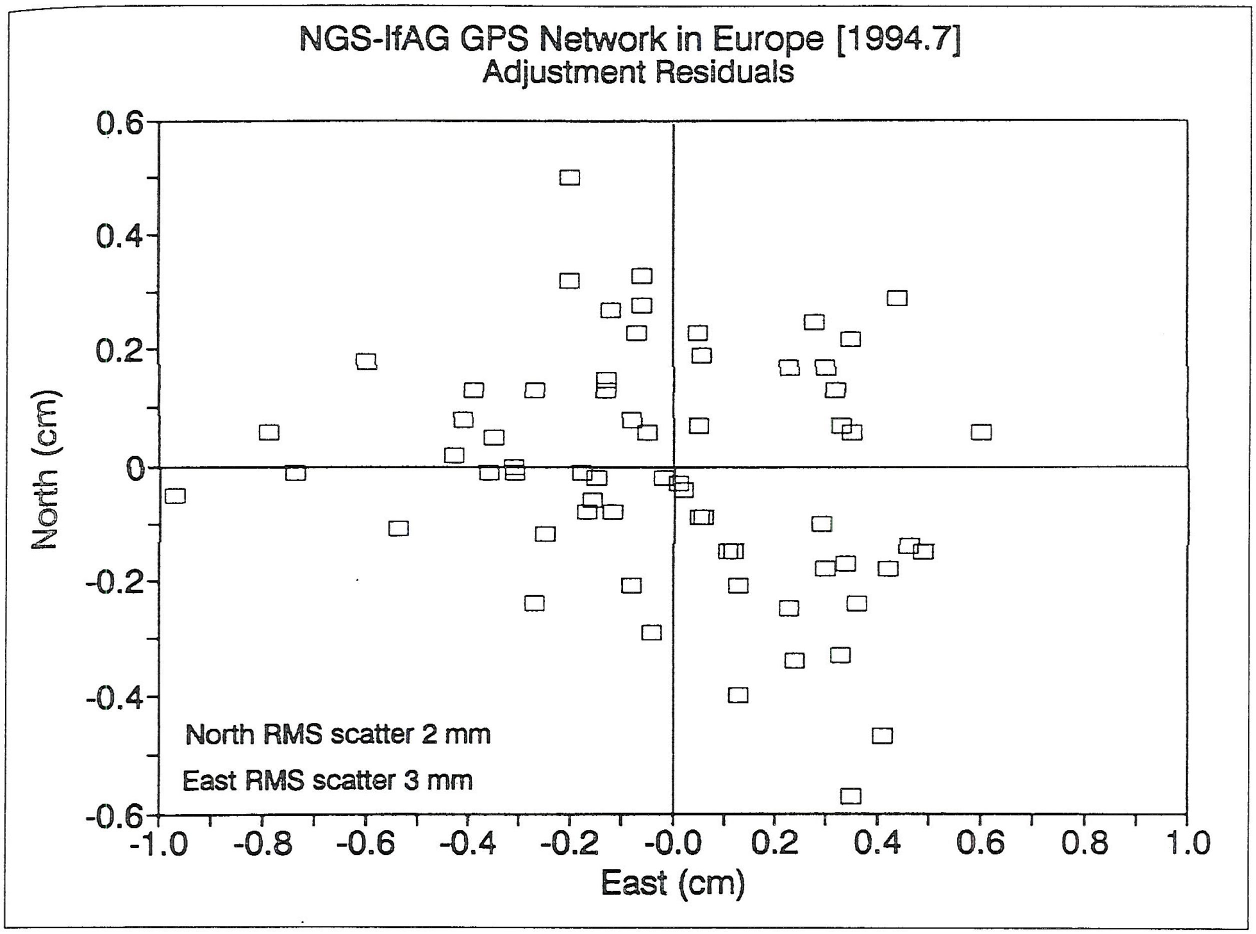


Figure 3. Adjustment residuals plotted on geodetic horizon plane.

been actively involved in determining the transformation parameters between EUREF89 and the ITRF series. This maintains continuity between the two reference frames and facilitates the transformation of coordinates between GPS determined ITRF coordinates at any epoch and the adopted ETRF89.

The conversion between the values obtained in this project (referred to the ITRF92, at epoch t_c = 1994.7) and the ETRF89 could be established according to the following equation (Boucher 1994):

$$\begin{Bmatrix} x \\ y \\ z \end{Bmatrix}_{ETRF89} = \begin{Bmatrix} x(t_c) \\ y(t_c) \\ z(t_c) \end{Bmatrix}_{ITRF92} + \begin{Bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{Bmatrix}$$

$$+ \begin{bmatrix} 0 & -\omega_3 & \omega_2 \\ \omega_3 & 0 & -\omega_1 \\ -\omega_2 & \omega_1 & 0 \end{bmatrix} \begin{Bmatrix} x(t_c) \\ y(t_c) \\ z(t_c) \end{Bmatrix}_{ITRF92} (t_c - 1989.0)$$

where

$\Delta x, \Delta y, \Delta z$ = shifts based on a global transformation ITRF92→ITRF89 including scale, and

$\omega_1, \omega_2, \omega_3$ = rotations from 1992 back to 1989 due to motion of European plate.

The adopted values for the above six parameters were also given by Boucher (1994) as:

Δx = 3.8 cm
Δy = 4.0 cm
Δz = -3.7 cm
ω_1 = 0.21 mas/year
ω_2 = 0.52 mas/year, and
ω_3 = -0.68 mas/year,

where 1 mas = 0″.001.

Using the previous equation in conjunction with the above parameters, the position of the stations given in Table 2 were transformed from ITRF94, epoch 1994.7 to ETRF89. A preliminary set of coordinates is presented in Table 3. Final values will be released after comparisons with IfAG results are complete and consistency with the rest of the EUREF geodetic stations has been confirmed.

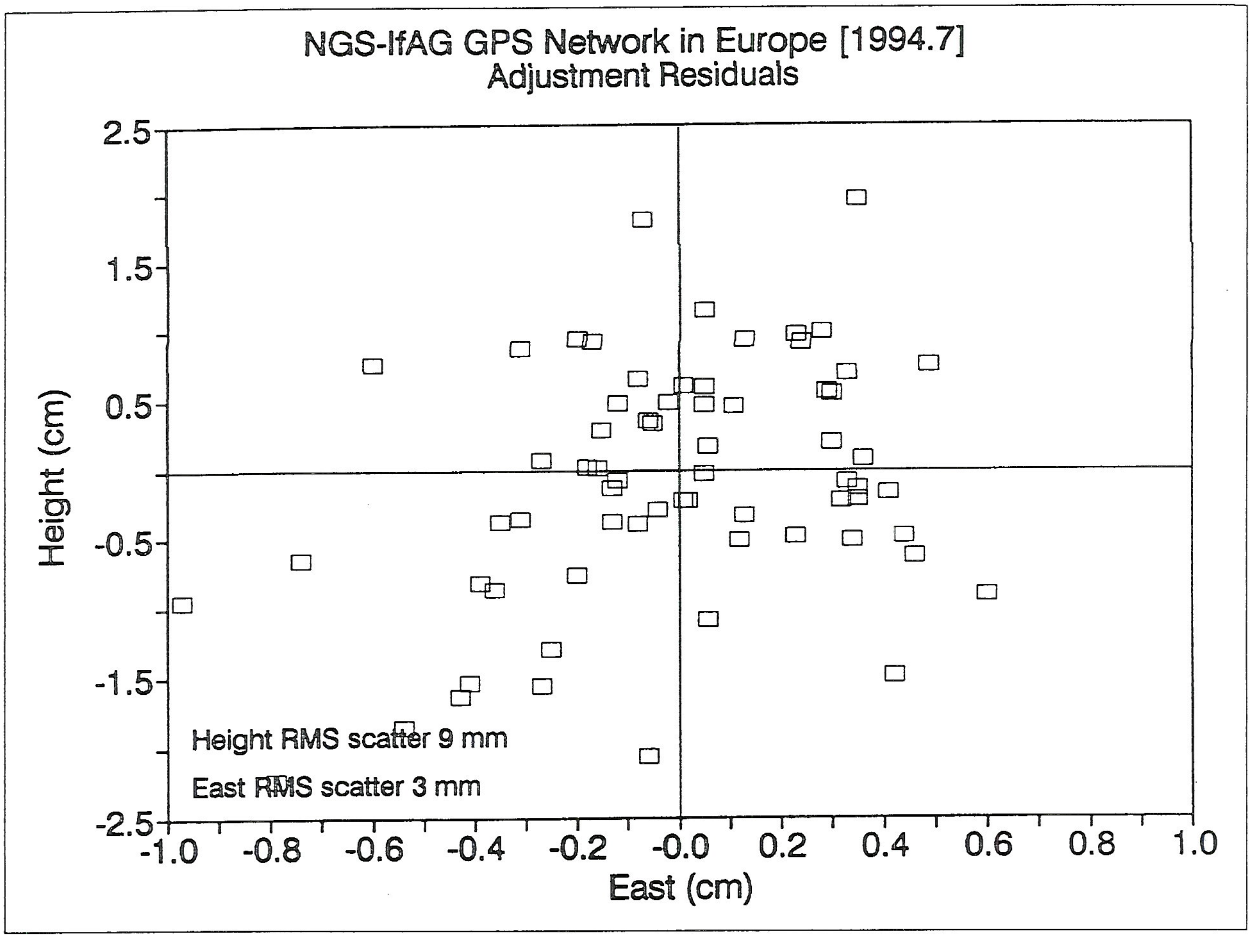


Figure 4. Adjustment residuals plotted on geodetic meridian plane.

Conclusion

Considering the quality of the results obtained, the objectives of NGS with respect to the GPS project in Romanian have been fully accomplished. NGS has put in place a very accurate geodetic reference network that will ensure that future geodetic and cartographic operations in the country will meet the most stringent geodetic and mapping requirements. This is only a first step in the arduous task of covering the land with more GPS points at the optimum level of densification. Conceptually, however, the methodology is similar and could converge on the production of a unique reference system by consciously exploiting the most advanced technology. Only then could all activities which relate to geodesy, cadastre, cartography, and GIS be expressed in an accurate, commonly defined, spatial framework.

ACKNOWLEDGMENTS

An abridged version of this paper was presented at the International Symposium and Exhibition: GPS Technology Applications held in Bucharest, Romania, September 26-19, 1995.

Many people contributed to the success of this project and were directly involved in the variety of facets that this complex project entailed. In particular we would like to thank the following participants: Professor Dr.-Ing. H. Seeger and Dipl.-Ing H. Habrich (IfAG); D. Benea (MAA); I. Buse, A. Bordea, and M. Gavrilescu (IGFCOT); and last, but not least, many colleagues at NGS and BLM who were involved in the planning and observational aspects of the project.

REFERENCES

Ádám, J., A. Kenyeres, T. Borza, G. Csapó, P. Lévai, Z. Németh, and L. Tóth. 1994. National Report of Hungary. In E. Gubler and H. Hornik, eds. *Subcommission for the European Reference Frame (EUREF). Publication No. 3*. Munich, Germany: Bayerische Kommission für die Internationale Erdmessung, 291-302.

Altamimi, Z., and C. Boucher. 1993. ITRF92 Coordinates. *IGS Electronic Mail* mess. no. 0421.

Benea D., and I. Buse. 1995. Tehnologia GPS in sprijinul procesului de aplicare a Legii Fondului Funciar, proces

	x	*y*	*z*
	(m)	(m)	(m)
CONSTANTA	4023362.284	2190844.148	4422995.304
DEALUL PISCULUI	4098300.085	2008691.060	4440543.519
MOSNITA	4153382.582	1623172.944	4545098.631
OSORHEI	4034633.574	1631849.524	4647381.707
SIRCA	3858208.894	1983192.009	4660288.026
SFÎNTU-GHEORGHE	4005316.998	1937791.871	4555275.971
STANCULESTI	4145351.554	1840743.920	4469798.231
MAKO, Hungary	4128720.700	1557707.358	4589954.299
PENC, Hungary	4052449.823	1417680.917	4701406.960
SOPRON, Hungary	4125619.064	1230225.946	4690656.180
TARPA, Hungary	3939065.887	1635574.673	4726647.178
TENKES, Hungary	4224902.817	1390480.241	4556477.655
GABROVO, Bulgaria	4227590.075	1996278.252	4324909.574
KAVARNA, Bulgaria	4083131.639	2205288.791	4361084.202
SOFIA, Bulgaria	4319372.436	1868687.557	4292063.792
VIDIN, Bulgaria	4233068.673	1773729.928	4414410.424
YIGILKA, Turkey	4117362.030	2517076.907	4157679.092

Table 3. Preliminary station cartesian coordinates [EUREF, ETRF89].

prioritar in cadrul Programului de Reforma a Agriculturii din Romania. *Proceedings International Symposium and Exhibition: GPS Technology Applications, September 26-29 1995, Bucharest.* Silver Spring, Md.: National Geodetic Survey, 21-24.

Boucher, C. 1994. Specifications for reference frame fixing in the analysis of a EUREF GPS campaign. In E. Gubler and H. Hornik, eds. *Subcommission for the European Reference Frame (EUREF). Publication No. 3.* Munich, Germany: Bayerische Kommission für die Internationale Erdmessung, 26-9.

Boucher, C., Z. Altamimi, and L. Duhem. 1994. Results and analysis of the ITRF93. *IERS Technical Note 18.* Paris: Central Bureau of IERS, Observatoire de Paris.

Buse, I., and D. Benea. 1995. Reteaua geodezica spatiala a României, realizari si perspective. *Proceedings International Symposium and Exhibition: GPS Technology Applications, September 26-29, 1995, Bucharest.* Silver Spring, Md.: National Geodetic Survey, 25-32.

Challstrom, C. W. 1995. Surveying support for eastern Europe. *1995 Technical Papers, ACSM Annual Convention* 1:121-129. Bethesda, Md.: American Congress on Surveying and Mapping.

Feissel, M., and D. Gambis. 1993. The International Earth Rotation Service: Current results for research on Earth rotation and reference frames. *Advances in Space Research* 13(11): 143-50.

Fejes, I., T. Borza, I. Busics, and A. Kenyeres. 1993. Realization of the Hungarian Geodynamic GPS Reference Network. *Journal of Geodynamics* 18(1-4): 145-52.

Fejes, I., I. Busics, M. Gazsó, and A. Kenyeres. 1994. A Közép-európai GPS Geodinamicai Referencia Hálózat. *Geo. és Kart.* 46(5-6): 254-64.

Federal Geodetic Control Committee. 1988. *Geometric geodetic accuracy standards and specifications for using GPS relative positioning techniques. Version 5.0.* Silver Spring, Md.: Federal Geodetic Control Committee, National Geodetic Survey, National Geodetic Information Branch.

Leick, A. 1995. *GPS satellite surveying.* 2nd edn. New York: Wiley–Interscience.

Leigh, G. E., and C. L. Smith. 1995. Romania Project, 1994. NGS Internal Report. Silver Spring, Md.: National Geodetic Survey.

Marjanovic, M., E. Reinhart, and H. Seeger. 1995. Preliminary results of the EUREF from 1994 GPS Campaign. *Proceedings International Symposium and Exhibition: GPS Technology Applications, September 26-29, 1995, Bucharest.* Silver Spring, Md.: National Geodetic Survey, 195-200.

McCarthy, D. D., ed. 1992. IERS Standards (1992). *IERS Technical Note 13.* Paris: Central Bureau of IERS, Observatoire de Paris.

Milev G., M. Minchev, and G. Valev. 1994. National Report of Bulgaria. In E. Gubler and H. Hornik, eds. *Subcommission for the European Reference Frame (EUREF). Publication No. 3.* Munich, Germany: Bayerische Kommission für die Internationale Erdmessung, 256-63.

Schenewerk, M. 1993. MGPS-PAGE3 users manual. OES Internal Document. Silver Spring, Md.: NOAA.

Seeger, H. 1994. EUREF. The new European Reference Datum and its relationship to WGS-84. *FIG XX Congress, Commission 5,* Melbourne, Australia, March 5-12, 1994.

Seeger, H., P. Franke, and E. Reinhart. 1995. EUREF Status Report 1994/1995. *Proceedings International Symposium and Exhibition: GPS Technology Applications, September 26-29, 1995, Bucharest.* Silver Spring, Md.: National Geodetic Survey, 185-94.

Soler, T., W. E. Strange, and J. S. Ferguson. 1991. Geodetic coordinate systems in Florida: GPS contribution. *Journal of Surveying Engineering* 117(2): 77-96. ◼