Rigorous Geodetic Point Positioning in Mexico

Antonio HERNANDÉS-NAVARRO (Mexico) and Tomás SOLER (USA)

Key words: GPS derived Datum; Mexico; OPUS; National Spatial Reference System.

SUMMARY

Thanks to the scientific cooperation between the General Direction of Geography of the Mexican *Instituto Nacional de Estadística, Geografía e Informática* (INEGI) and the National Geodetic Survey (NGS) of the U.S., is now feasible to accurately position points located within the Mexican territory using GPS observations and the access, through Internet, to NGS' OPUS (On-line Positioning User Service). This service, free of charge, determines with minimum delay, the final coordinates referred to the new -in process of official adoption- Mexican datum, specifically, ITRF 2000, epoch 2004.0. Therefore, OPUS could be used in Mexico for geodetic, topographic, cartographic, GIS, and cadastral work, obtaining always consistent results with the reference frame that defines the Mexican geocentric datum the basis for all cartographic work in the country. Important to this new development is the role of the GPS stations belonging to the Mexican *Red Geodésica Nacional Activa* (RGNA) whose data take part in the OPUS process to achieve the best positioning results in the Mexican Republic. Most of the information presented here was published in the trade journal *The American Surveyor*.

RESUMEN

Gracias a la cooperación científica entre la Dirección General de Geografía del *Instituto Nacional de Estadística, Geografía e Informática* (INEGI) de México y el National Geodetic Survey (NGS) de los estados Unidos, ahora es posible el posicionamiento puntual preciso localizado dentro del territorio mexicano usando observaciones GPS y el acceso, a través de INTERNET, a OPUS del NGS (Servico a usuarios de posicionamiento en línea, por sus siglas en inglés). Este servicio, libre de costo, determina con retraso mínimo, las coordenadas finales de referencia en nuevo datum mexicano, en proceso de adopción oficial, ITRF 200 época 2004.0. Por ello, OPUS puede usarse en México para trabajos geodésicos, topográficos, cartográficos, GIS y catastrales, obteniéndose siempre resultados consistentes con el marco de referencia que define el datum geocentrico mexicano que es la base para todos los trabajos cartográficos en el país. Algo importante en este nuevo desarrollo es el pael de las estaciones GPS pertenecientes a la *Red Geodésica Nacional Activa* (RGNA) de México cuyos datos se consideran en los procesos de OPUS para alcanzar los mejores resultados posicionales en la República Mexicana. Gran parte de la información presentada en esta contribuciónha sido publicada en el revista *The American Surveyor*.

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1. INTRODUCTION

The National Geodetic Survey (NGS) an Office of the U.S. National Oceanic and Atmospheric Administration (NOAA) released in May, 2002, a Web-based utility, called the On-line Positioning Users Service (OPUS), which has revolutionized how accurate positional coordinates are obtained [see Mader et al., 2003; Soler et al., 2006b]. In particular, OPUS enables its users to submit a GPS data file to NGS via the Web; whereby the data will be processed using NGS computers and software to determine the positional coordinates associated with the location where the data was observed. Each data file is processed with respect to three continuously operating reference stations (CORS), and the user receives the computed coordinates via email, usually within minutes. For details on the use of this utility go to the Web page: www.ngs.noaa.gov/OPUS/ .

Once OPUS was well established in the United States and a number of Caribbean and Central American countries, a dialogue ensued between Mexico's *Instituto Nacional de Estadística, Geografía, e Informática* (INEGI) and NGS to provide OPUS capability within the Republic of Mexico. The *Direccción General de Geografía* (DGG) is the office of INEGI responsible, among other duties, for the establishment, maintenance, and densification of the national geodetic network. DGG is also in charge of producing Mexican cartography products, primarily topographic maps at 1:50,000 and 1:20,000, which provide the backbone of the country's natural resources inventory (http://www.inegi.gob.mx/inegi/). Open communication between scientists at DGG and NGS resolved some minor logistic problems, and in March of 2006, OPUS was incorporated as a new Internet service to determine positions in Mexico.

Similar to the establishment of the U.S. CORS network, INEGI has developed their own *Red Geodésica Nacional Activa* (RGNA) [National Active Geodetic Network]. The RGNA has been in operation for more than 12 years [Hernández-Navarro, 2004], consequently, Mexico, along with the United States, pioneered the establishment of active CORS networks with the primary intention of creating the required infrastructure to support geodetic work and precisely define the national spatial reference systems (see Fig. 1). As of this writing, OPUS only uses 12 of the 14 RGNA sites where PS data is gathered continuously. The other two sites (TAMP and VIL2) will be added in the future, after some inherent technical problems are cleared.

Scientific collaboration between INEGI and NGS on geodetic matters has existed for many years. The extension of OPUS to Mexican territory [Soler and Hernández-Navarro, 2006] is the culmination of many years of constant interaction and collaboration between scientists of both organizations.

Those familiar with OPUS in the United States should be able to use it with the same ease in Mexico. However, it is important to emphasize that the coordinates reported for locations in Mexico are referred to the newly adopted Mexican datum and not to the NAD83 (CORS96), as is the case for U.S. locations.

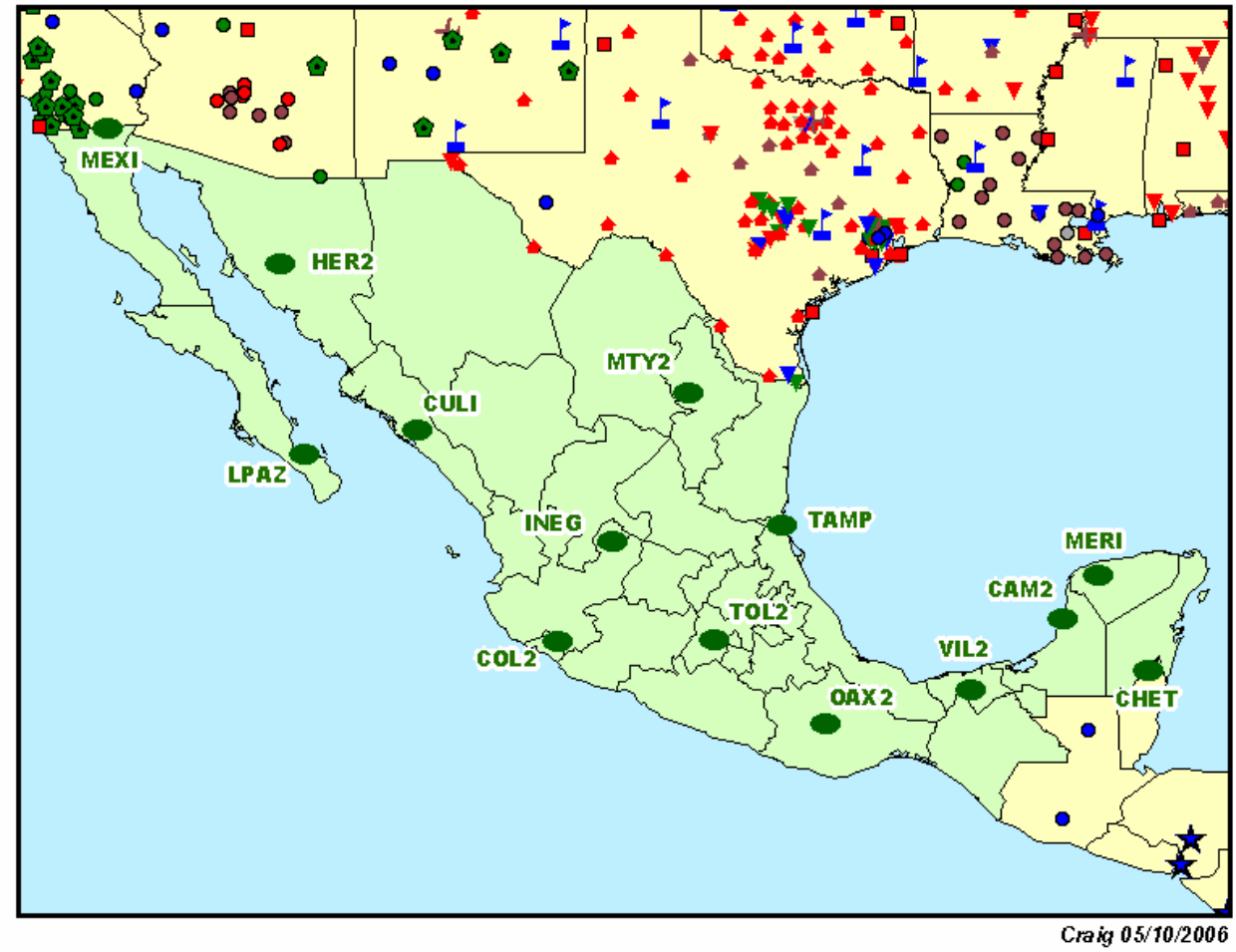

Fig. 1 Active control stations and/or CORS in and around Mexico.

2. MEXICAN DATUM

As in the United States, Mexico has changed its national geodetic datum on several occasions. Until 1993, all Mexican geodetic and cartographic products were referred to the North American Datum of 1927 (NAD27) [Villasana, 1974]. Radical advances in GPS technology convinced INEGI top management to transition from the classical, mainly two dimensional methods, to more accurate, three-dimensional, GPS-based methodology. Thus, INEGI adopted a geocentric 3D coordinate frame as the basis for all its national geodetic and mapping needs. The selected frame was the International Terrestrial Reference Frame of 1992 (ITRF92), epoch 1988.0 [Soler et al., 1996]. However, recently, Mexico has further improved the definition of its geodetic reference frame by switching to ITRF2000, epoch 2004.0 [González-Franco and Gómez-Moreno, 2006]. The reference surface used to define

the datum remains the ellipsoid of the Geodetic Reference System, as adopted by the International Association of Geodesy in December 1983, namely GRS80 [Moritz, 2000]. The implementation of this new geocentric datum permits the integration of all Mexican geodesy, surveying, cadastral work, GIS, and mapping into a modern framework consistent with current accuracies obtainable through modern Global Navigation Satellite System (GNSS) methodologies.

3. OPUS OUTPUT IN MEXICO

For the reasons explained above, and in order to avoid unnecessary datum transformations by the user, the results provided by OPUS for locations in Mexico are referred to the Mexican datum. Therefore, besides given coordinates on the current frame (ITRF2000) at the observation epoch, the information given by OPUS –when in Mexico- is composed of the coordinates in Cartesian and geodetic versions, and UTM coordinates (see Fig. 2) referred to

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                        NGS OPUS SOLUTION REPORT
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       USER: User.Mexico@noaa.gov                    DATE: March 07, 2006
 RINEX FILE: ineg0620.06o                            TIME: 15:11:28 UTC


   SOFTWARE: page5  0601.10 master3.pl            START: 2006/03/03  00:00:00
  EPHEMERIS: igr13645.eph [rapid]                  STOP: 2006/03/04  00:00:00
   NAV FILE: brdc0620.06n                      OBS USED: 45959 / 47835   : 96%
   ANT NAME: TRM29659.00     NONE           # FIXED AMB:   172 /   209   : 82%
 ARP HEIGHT: 0.0705                        OVERALL RMS: 0.027(m)


  REF FRAME: ITRF00(EPOCH:2004.0000)          ITRF00 (EPOCH:2006.1686)

          X:     -1260435.728(m)   0.190(m)        -1260435.752(m)   0.190(m)
          Y:     -5788547.385(m)   0.368(m)        -5788547.387(m)   0.368(m)
          Z:      2360340.145(m)   0.202(m)         2360340.131(m)   0.202(m)

        LAT:   21 51 22.15342      0.039(m)       21 51 22.15291      0.039(m)
      E LON:  257 42 56.86851      0.114(m)      257 42 56.86771      0.114(m)
      W LON:  102 17  3.13149      0.114(m)      102 17  3.13229      0.114(m)
     EL HGT:         1888.125(m)   0.445(m)             1888.126(m)   0.445(m)

                         UTM COORDINATES
                          UTM (Zone 13)
 Northing (Y) [meters]     2419383.069
 Easting (X)  [meters]      780685.164
 Convergence  [degrees]       1.01169451
 Point Scale                  1.00057359
 Combined Factor              1.00054827
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Fig 2. OPUS report for users in Mexico

the adopted Mexican datum. Depending on the location of the observed (rover) point, OPUS could select as reference stations, CORS sites, Mexican RGNA sites, or International GNSS Service (IGS) sites. The currently available option of selecting, as reference stations, any three sites remains unchanged. As usual, the OPUS algorithm will select –according to the

quality of the data- three reference stations; transform them to the frame ITRF2000 and observation epoch; compute a solution on this frame and epoch; and transform the results to the epoch 2004.0 using the NUVEL1A model for plate tectonics and the software Horizontal Time- Dependent Positioning (HTDP) developed at NGS [Snay, 1999]. Unquestionably, this common effort between INEGI and NGS fulfills the desire of many private engineering and geomatic companies in Mexico and the US that requested the availability of OPUS in Mexico to simplify the surveying routine without loosing the accuracy of the final product.

4. RGNA DATA (MEXICAN NATIONAL ACTIVE NETWORK)

People observing inside Mexico desiring to do their own data processing using RGNA sites can access the GPS data from these stations at http://www.ngs.noaa.gov/CORS/ and/or http://www.inegi.gob.mx/geo/default.asp?c=592. NGS provides the same type of information for both CORS and RGNA sites. This includes the 60 day plots (Fig. 3) showing the variation

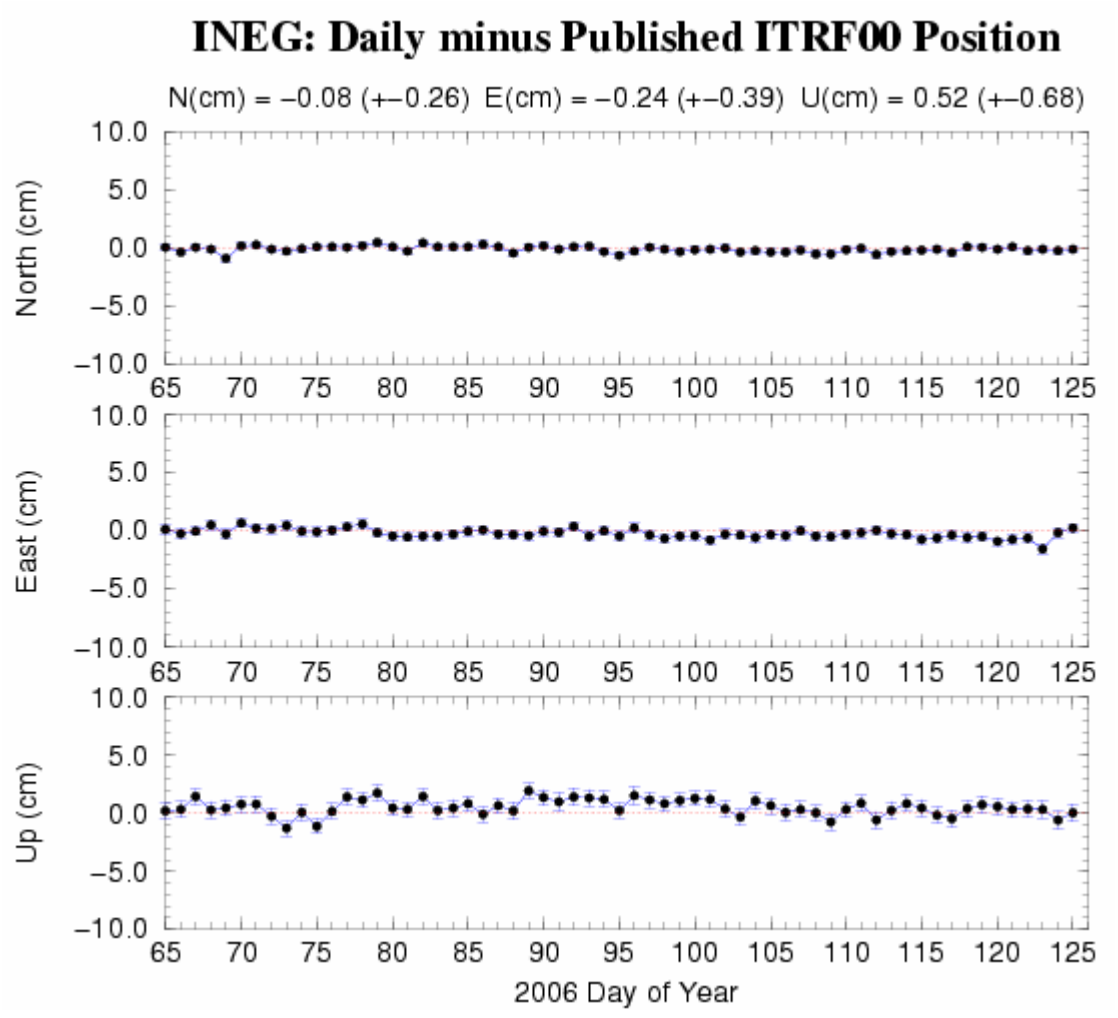

Fig. 3 Variation of coordinates at the INEGI site during a time period of 60 days

between the adjusted coordinates of the daily solutions of all GPS data from the adopted coordinate values. The variations are plotted along the north, east, and up (vertical) components. The effect caused by the rotation of the North American tectonic plate has been subtracted. The mean (bias) of the residuals as well as the RMS of the differences are given at the top of the figures. Specifically, Figure 3 shows the variations between adopted and determined positions for one particular site, INEG, located at INEGI headquarters in Aguascalientes. Notice that in this particular example the determined coordinates agrees well with the horizontal (red) broken line shown on the figure that represents the adopted (published) values.

5. MEXICAN GEOID

The first gravimetric Mexican geoid (MEXICO97) was computed in 1997, by NGS, with the collaboration of INEGI (http://www.ngs.noaa.gov/GEOID/MEXICO97/). Recently, INEGI has independently determined a new gravimetric geoid for Mexico where it has incorporated all available gravimetric information including important gravimetric campaigns completed in the last few years. This Mexican geoid (Fig. 4) is referred to as the GGM05 and is available at http://mapserver.inegi.gob.mx/SIAG/?c=692. This geoid should be used for all orthometric heights computation in Mexico. GPS users interested in knowing the orthometric

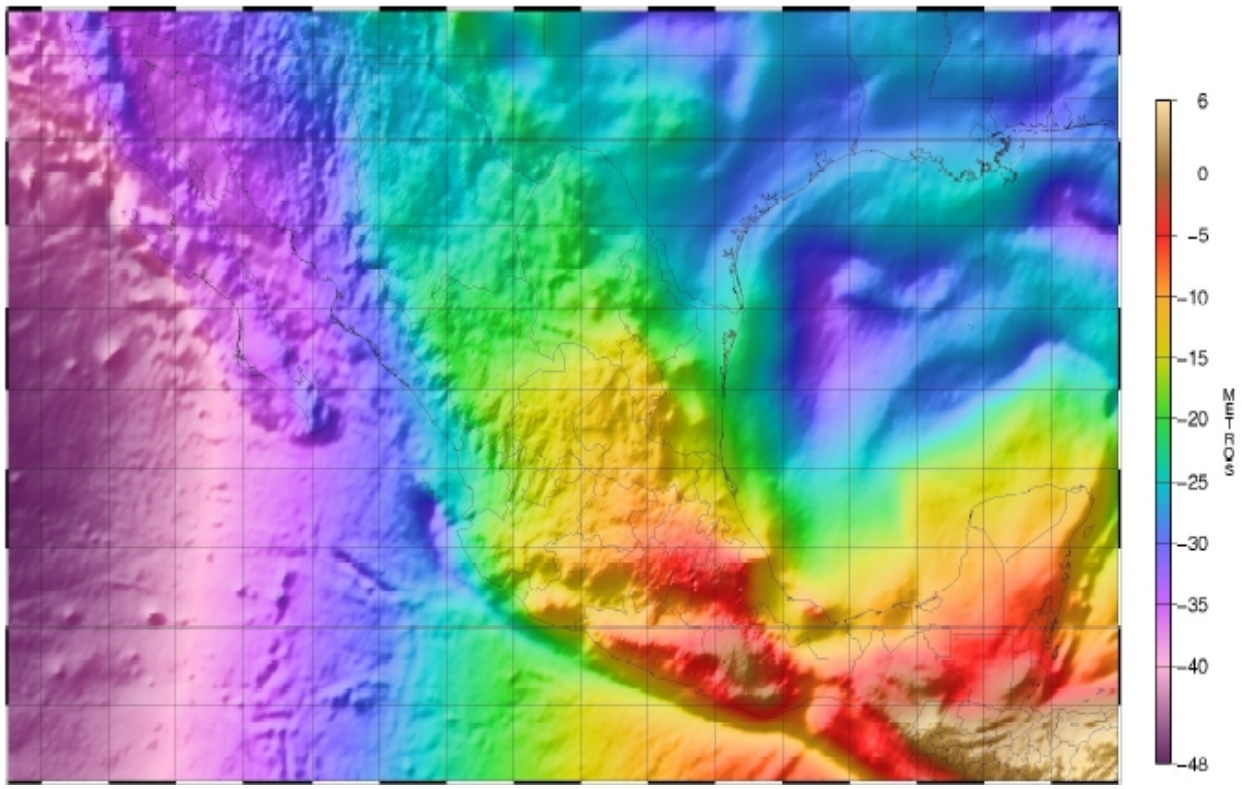

Fig. 4 INEGI's Mexican geoid (GGM05)

height of any point determined by OPUS should go to the INEGI Web page mentioned previously and click the word “calcular”. A window will open where, interactively, the user can introduce the latitude and longitude from the OPUS report and get the geoidal undulation (geoid height) of the point. INEGI is working to improve this geoid and, at this writing, produces geoids heights with an absolute RMS error of about 30 cm [Muñoz-Abundes and Ávalos-Naranjo, 2006]. Nevertheless, for relative determinations of orthometric heights, most of the common errors between two points will be eliminated and the results should be accurate to within a few centimeters. Accuracies of OPUS results, in general, were previously discussed by Soler et al. [2006a].

Questions in Spanish about OPUS in Mexico should be addressed through the Web page: http://www.inegi.gob.mx/lib/buzon.asp?s=geo. Questions in English should follow the standard OPUS approach by sending an e-mail to ngs.opus@noaa.gov .

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BIOGRAPHICAL NOTES

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