Precise Georeferencing Using On-line Positioning User Service (OPUS)

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Key words: GPS services; OPUS; National Spatial Reference System.

SUMMARY

In 2002, the National Geodetic Survey (NGS), an office of the National Oceanic and Atmospheric Administration (NOAA) in the United States, developed a web-based service called OPUS (On-line Positioning User Service) to provide GPS users easier access to the country's National Spatial Reference System (NSRS). OPUS allows professionals in the fields of geodesy, surveying, mapping, and GIS to submit their GPS data files to NGS headquarters, via the web, where they are processed to determine associated positional coordinates. The results are based on NGS' determined coordinates from its Continuously Operating Reference Stations (CORS) and/or the sites of the International GNSS Service (IGS). Recent investigations performed in the United States suggest, for precise surveying and geodetic applications the length of the observing sessions should be two or more hours. Results drastically improved for solutions containing more than 4 hours.

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1. INTRODUCTION

In recent years several governmental and academic organizations have provided GPS professionals with easy-access, on-line GPS processing services, capable of determining accurate geocentric positions using GPS observations. Among the best known are: AUSPOS [Dawson et al., 2004]; Auto-GIPSY [Zumberge, 1999]; OPUS [Mader et al., 2002]; PPP [Tétreault et al., 2005]; and SCOUT [SOPAC, 2004]. For some preliminary comparisons between these online public services see Macdonald [2002] and Ghoddousi-Fard and Dare [2006].

The objective of this paper is to describe the version of GPS processing service -developed in the U.S. by the National Geodetic Survey (NGS)- a Program Office of the National Oceanic and Atmospheric Administration (NOAA). Named On-line Positioning User Service (OPUS), its principal characteristic is the application of a simple relative position methodology. However, results depend on the quality of data and accurate a priori coordinate use, of a network of GPS active control points that are continuously operated. NGS manages such a network, the National Continuously Operating Reference Station (CORS) and its Cooperative counterpart, both serving a diverse number of applications [Snay et al., 2002a; http://www.ngs.noaa.gov/CORS/).

Since May, 2002, NGS has provided the North American surveying community with OPUS processing, free of charge. The history of OPUS has been one of success. GPS users overlapping the fields of geodesy, surveying, cadastral work, GIS, and mapping viewed the availability of an important service such as OPUS positively, and have become constant users of the service when accurate positioning is required.

OPUS is currently available in North (Canada and Mexico) and Central America (except Panama); several island nations in the Caribbean; and Surinam, Guyana and Peru in South America. Besides CORS and the International GNSS Service (IGN) sites, OPUS also relies upon the Mexican National Active Geodetic Network (*Red Geodésica Nacional Activa*, RGNA.) More information about the particulars of OPUS in Mexico can be found in Soler and Hernández-Navarro [2006].

2. OPUS CHARACTERISTICS

OPUS is an automatic service that requires the user to input only a minimal amount of information; its instructions are self explanatory and its Web page contains enough details to be followed easily (http://www.ngs.noaa.gov/OPUS/). However, OPUS has a few restrictions users should be aware of: first, and most importantly, OPUS provides a point static solution.

Second, a minimum of 2 hours of GPS observations are recommended by NGS to obtain surveying-geodetic accuracies. Third, a maximum of 48 hours is permitted (the GPS data only can cross midnight once). Forth, the submitted data file must contain dual-frequency (L1/L2) carrier phase observables. Finally, no GLONASS observations are processed at this time, although in the future, they may be incorporated, along with Galileo, as the constellation of this European navigational system becomes available.

Once data are received by NGS they are processed automatically with NGS computers and software. The driving engine of OPUS is PAGES software, developed by NGS scientists, encompassing many years of research. The position of the remote ("static rover") point is determined with respect to three suitable CORS (and/or RGNA, IGS) sites. The solution is sent to the user by e-mail after a few minutes.

The methodology is very straightforward. OPUS processes three baselines, each involving the rover and a CORS. The three final positions are averaged by a simple mean, assuming all results have equal weights. Maximum differences between the three determined position components are printed as statistics (the so-called "peak-to-peak" errors).

To estimate the position of the remote station, the following algorithm is implemented in OPUS. Distances to every site in the CORS network are computed. The results are sorted by increasing distance, and the five closest CORS sites are originally selected. Initially, the data quality of the closest 3 sites are checked using TEQC (Translate Edit Quality Control), software developed at UNAVCO [Estey and Meertens, 1999], according to the following criteria:

- The data covers the time span of the remote station
- More than 80% of data overlaps the remote station data window
- Low multipath effects must be assured
- If the above conditions are not fulfilled, replace station #3 with #4 (then #5)

Start single baseline solutions using CORS stations 1 through 3
- Check quality of solution
- If bad solution, replace CORS # 3 with #4 (then #5)

OPUS admits several types of data formats:

  - RINEX (Receiver Independent Exchange format) uncompressed
  - Manufacturers native/raw (binary) uncompressed; must go through TEQC
- Compressed archives of multiple files. Archive must contain RINEX (e.g. site123h.06o) or Hatanaka (e.g. site123h.06d)
- Compressed individual files. "Site123h.zip" must contain "site123h.06o" or "site123h.06d"

2.1 OPUS Options

Several options are available to the OPUS user in the US. Although the output of OPUS always provides as default a dual set of plane coordinates in the UTM projection and State Plane Coordinates (SPC) [Stem, 1989], the user has the option of selecting in advance the particular SPC applicable to the region of his location. This is convinient in situations where the observer is located near the border between regions.

Another option is to select or exclude any of the three base stations. However, this alternative may be more damaging than helpful to the final results if one considers that one of the selected/excluded sites may have bad/good observations that may negatively affect the solution.

A user can also inquire for more information, the so-called ”extended output”, in contrast with the typical default standard output. This option provides the user with more statistics, and results, in a pre-specified format that can be used to do a combined least squares adjustment of many baselines between different points invoking the ADJUST software developed by NGS.

A final option permits users to keep, without retyping, common parameters (antenna type, antenna height, etc.) that do not change, in any of the many files submitted for processing. The program will recognize, by the address of the e-mail, that the user wants to retain the same set of parameters in all its solutions.

3. STANDARD OUTPUT

Figure 1 shows the typical standard output received by OPUS users in the US. Among the information provided are the e-mail of the user; the observation file name; the solution run date and time; the version of PAGES software used toprocess the data; the ephemeris used (OPUS will use the best available among the three possibilities: final post-fit orbit, rapid post-fit orbit, and ultra-rapid predicted orbit); navigation file used; antenna type selected and height of antenna reference point (ARP) entered.

On the top right-hand of the OPUS output, the following information is provided: the start and end dates/times of the input file; the ratio and % of observations used in the solution; the ratio and % of fixed/total ambiguities; and the overall RMS of the solution.

On the central part of the printout, the information related to the position of the point is given. The reference frames and epochs are explicitly mentioned. The Cartesian (x, y, z) coordinates at the observation epoch referred to the ITRF2000 frame are printed on the right, accompanied by their corresponding peak-to-peak errors. The peak-to-peak errors represent the difference between the maximum and minimum value of a positional coordinate, as obtained from the three separate solutions. These peak-to-peak errors are thought to provide a more realistic measure of the quality of the determined positional coordinates than formal errors, determined through a simultaneous least squares estimation process.

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                              NGS OPUS SOLUTION REPORT
                              ========================

      USER: user.USA@noaa.gov                      DATE: June 08, 2006
RINEX FILE: gait0910.06o                             TIME: 11:18:51 UTC


  SOFTWARE: page5  0601.10 master2.pl             START: 2006/04/01  00:00:00
 EPHEMERIS: igs13686.eph [precise]                  STOP: 2006/04/01  23:59:00
  NAV FILE: brdc0910.06n                        OBS USED: 48924 / 51370   :  95%
  ANT NAME: AOAD/M_T        NONE             # FIXED AMB:   256 /   275   :  93%
ARP HEIGHT: 0.0                              OVERALL RMS: 0.020(m)

 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)            ITRF00 (EPOCH:2006.2480)

         X:      1095790.781(m)   0.010(m)          1095790.088(m)   0.010(m)
         Y:     -4831328.045(m)   0.017(m)         -4831326.598(m)   0.017(m)
         Z:      4003934.404(m)   0.019(m)          4003934.291(m)   0.019(m)

       LAT:   39  8  2.34044      0.004(m)        39  8  2.36961      0.004(m)
     E LON:  282 46 44.48128      0.014(m)       282 46 44.46647      0.014(m)
     W LON:   77 13 15.51872      0.014(m)        77 13 15.53353      0.014(m)
    EL HGT:           108.930(m)  0.024(m)                107.646(m)  0.024(m)
 ORTHO HGT:           140.647(m)  0.035(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 18)         SPC (1900 MD  )
Northing (Y) [meters]     4333993.903           162903.081
Easting (X)  [meters]      308035.021           380894.459
Convergence  [degrees]    -1.40216645          -0.13869297
Point Scale                1.00005376           0.99995997
Combined Factor            1.00003667           0.99994288

US NATIONAL GRID DESIGNATOR: 18SUJ0803533994(NAD 83)
```

Fig. 1 Standard OPUS output. CORS site GAIT was used as rover.

On the central left side of the printout, the curvilinear coordinates (latitude, longitude, ellipsoid height) referred to the NAD 83 (CORS96) geodetic datum and their peak-to-peak errors, are given. Below these coordinates the orthometric height of the point, based on the current geoid model, is given. Here it should be mentioned that in countries where NAD 83 is not the official datum, OPUS will give the final coordinates in the ITRF2000, epoch 1997.0 (except in Mexico that uses the epoch 2004.0).

Finally, at the end of the printout, the plane coordinates of the point referred to two mapping projections are also, explicitly, given. Thus, the user will find plane coordinates referred to the Universal Transverse Mercator (UTM) projection and the State Plane Coordinate (SPC) adopted by the state where the point is located, with other ancillary information (convergency, point scale, etc.). OPUS solutions in countries other than the U.S., will provide only UTM coordinates.

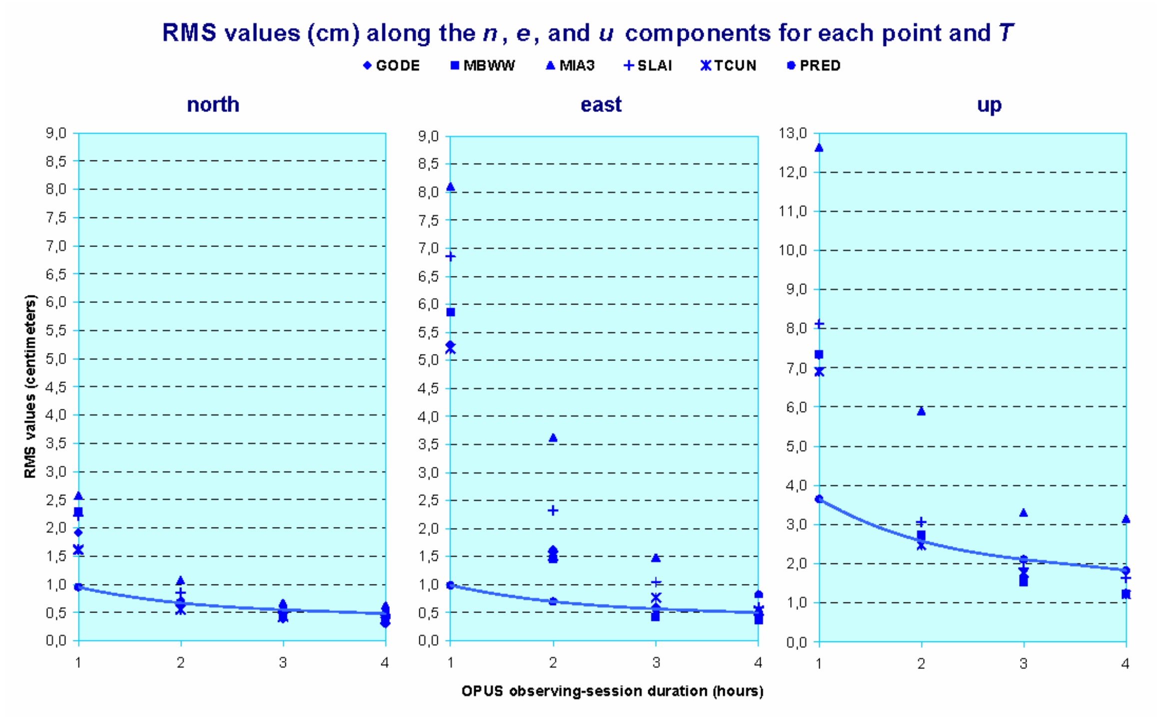

Fig. 2 OPUS results plotted against the predicted curve [equation (1)]. Note that the scale of the "up" plot differs from that of the "north" and "east" plots.

3.1 Guidelines for a Good Solution

An important premise for a good solution is to make sure the antenna type and height are correct. Other important statistics to be reviewed include:

- At least 90% of observations should be used
- At least 50% of the ambiguities should be fixed
- Overall RMS of the solution double difference residuals should seldom exceed 0.030 m.

In case of bad statistics, choose different CORS sites and re-submit the observation file.

4. OPUS ACCURACY

As mentioned before, the main engine driving OPUS is PAGES sofware. Previous studies by Eckl et al. [2001] and Snay et al. [2002] investigated the dependency of relative GPS solutions processed with PAGES, as a function of interstation distance and observing session duration. However, the minimum observation time window was limited to four, hours in these studies. As a result of this investigation, the RMS errors (expressed in cm) can be computed by this simple-to-remember empirical formula:

$$RMS\ (cm) = \frac{k}{\sqrt{T}} \begin{cases} k = 1.0; & horizontal(north\ and\ east) \\ k = 3.7; & vertical \end{cases} \tag{1}$$

where T denotes the duration of the observation session expressed in hours and k is a free parameter in units of cm$\sqrt{hr}$. A recent study performed by Soler et al. [2006] investigated how the accuracy of three-dimensional OPUS solutions was affected by the length of the observing session T, for T ranging from 1 h to 4 h. In this case five Continuous Operating Reference Stations (CORS) distributed widely across the nation were selected. Then, they were assumed to be rovers and processed using GPS data, for each rover with corresponding data from three of its nearby CORS. The results confirm the current OPUS policy that recommends static observations with a minimum of 2 h of GPS data (see Fig. 2). In particular, 2 h of data yielded a RMS error of 0.8, 2.1, and 3.4 cm in the north, east, and up components, respectively. Results drastically improve for solutions containing 3 h or more of GPS data.

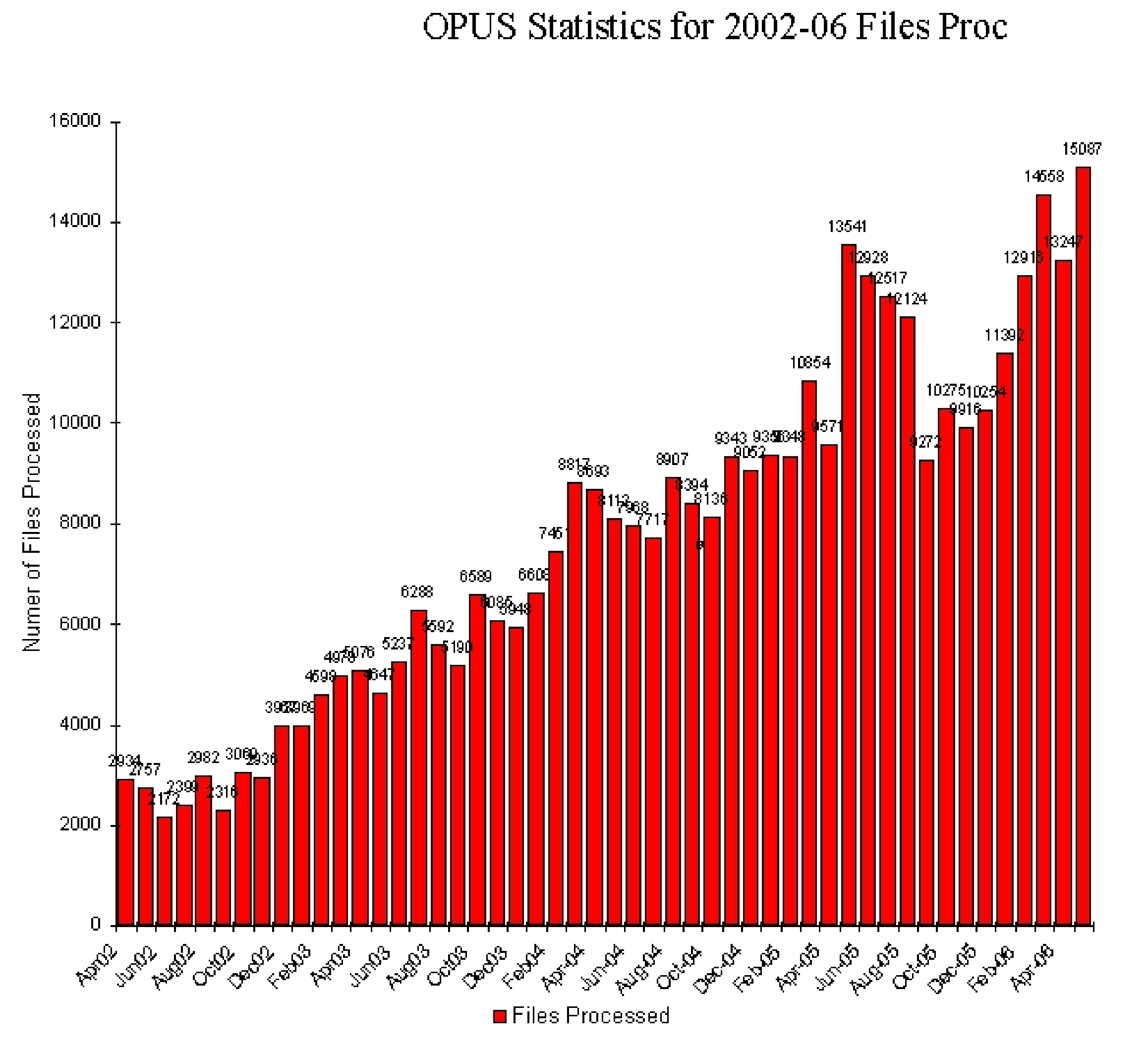

Fig. 3 Number of monthly OPUS files processed since April 2002 to May 2006

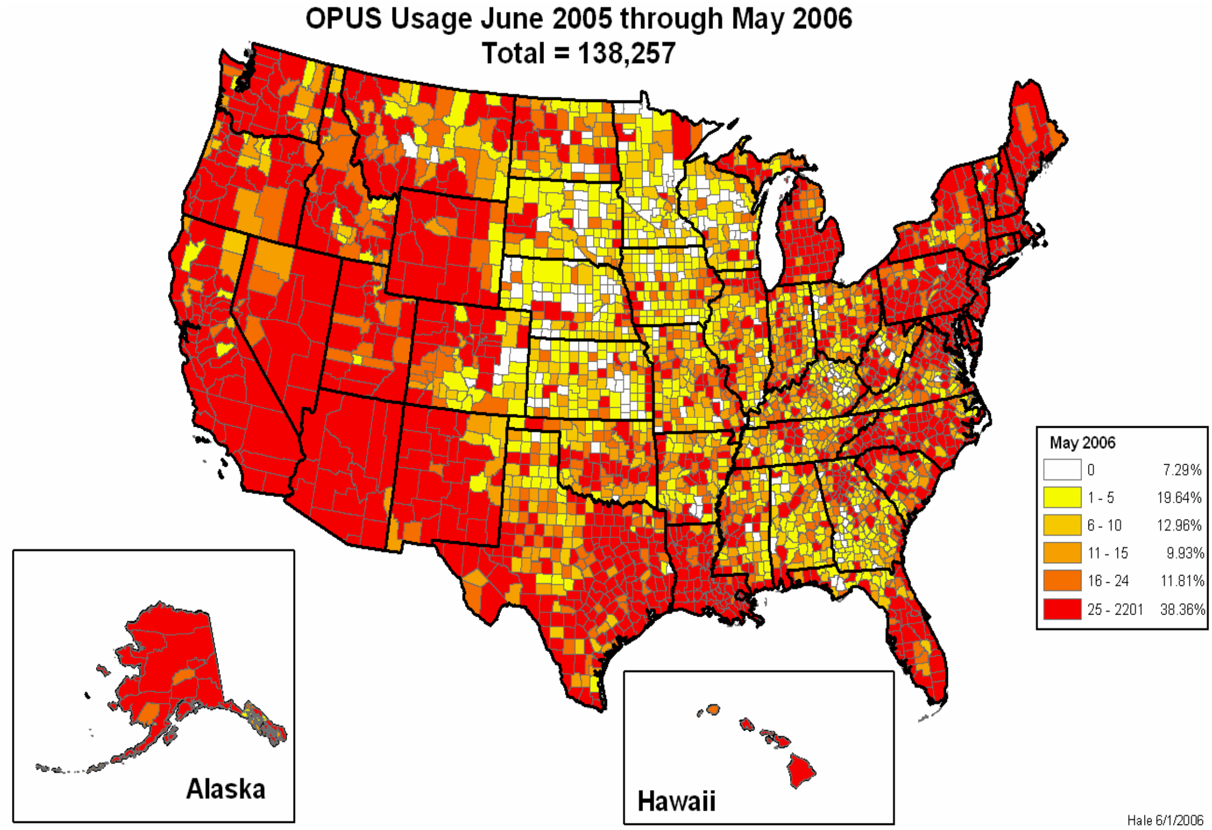

Fig. 4 OPUS files processed in the US, countywise, during one year period (06/05-05/06)

5. OPUS SUCCESS

OPUS software was developed at the end of 2001. Several improvements have been incorporated since beta testing was finalized and the service made available to the general public. The reader can have a better understanding of the steady progress attained by OPUS over the years by perusing two typical graphs presented here. Fig. 3 shows the total number of monthly files processed by OPUS during 2002-2006.

In Fig. 4, notice the total number of solutions were 138,257. Then, in Fig. 5, notice in red, the geographic location of all points processed on a typical day. All these plots, among others, could be accessed at the NGS CORS Newsletter Web site, where they are periodically updated [http://www.ngs.noaa.gov/CORS/Newsletter1].

Since OPUS' inception, about 21,000 unique users have performed OPUS solutions at least once.

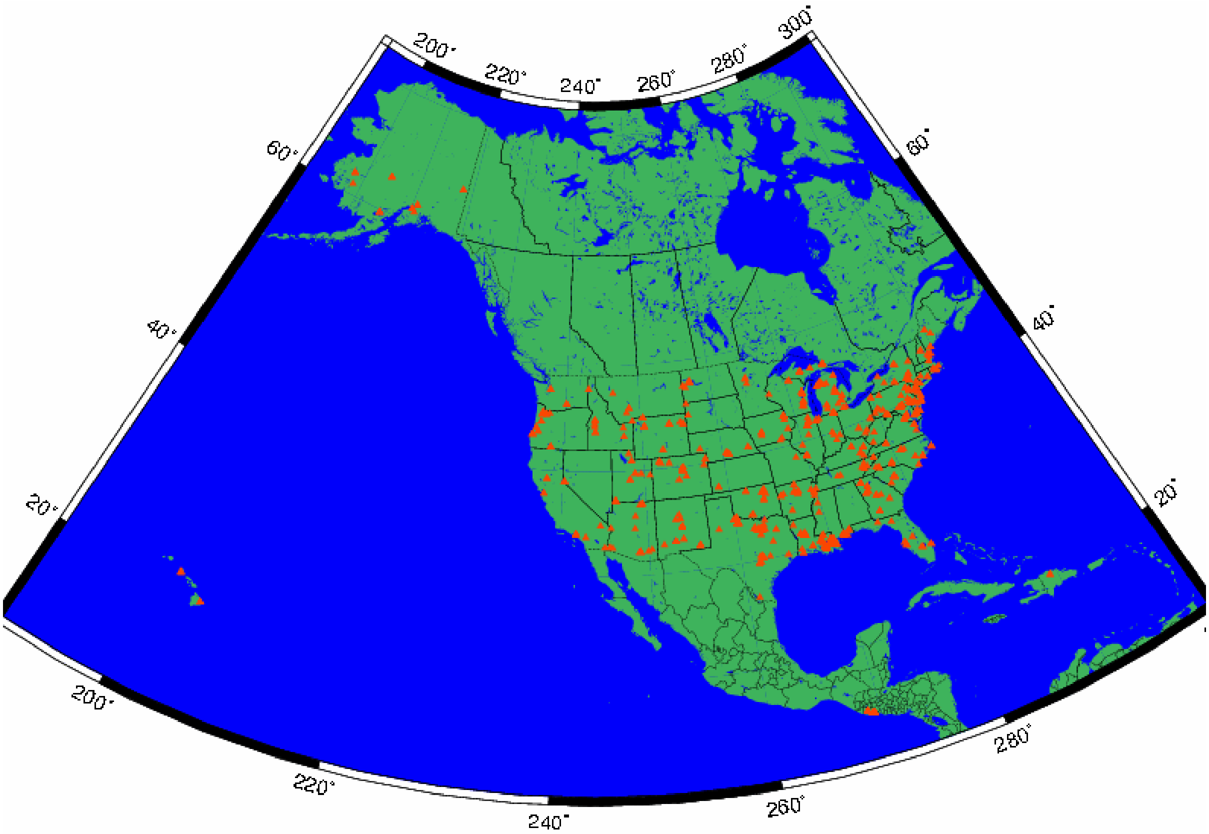

Fig 5 Geographic location of OPUS solutions processed on day 157 (June 6, 2006)

6. OTHER FLAVORS OF OPUS BEING DEVELOPED

NGS is currently trying to develop variations of OPUS, able to perform other functions. The effort is concentrated, at the moment, on two new versions of OPUS, named OPUS-DB and OPUS-RS, asbriefly described below.

6.1 OPUS-DB (Data Base)

This version of OPUS will open the possibility for US OPUS users to archive their results into the NGS data base and become part of the National Spatial Reference System (NSRS). OPUS solutions meeting certain criteria and accompanied by pre-specified sets of metadata describing the site environment, may be eligible for publication on Data Sheets from the NGS Integrated Data Base (IDB). Users submitting to the IDB must be registered with NGS to receive a user ID and password, and agree to the terms of this publication. The criteria for an OPUS solution to be accepted for integration into NSRS are:

- Use of a NGS calibrated GPS antenna
  - Minimum 4 h data span
  - Minimum 90% observations used
  - Minimum 80% fixed ambiguities

- More than 80% of data overlaps the remote station data window
  - Maximum 0.02m horizontal peak-to-peak
  - Maximum 0.04m vertical peak-to-peak

Assuming all metadata requirements (description of the location, photograhps, etc.) are fulfilled, and a final evaluation at NGS headquartes of the submitted OPUS solution, approved OPUS runs will be incorporated into the IDB; e.g. updating old marks whose positions were never before determined using GPS (e.g. bench marks, etc.) and entering new stations into the database.

6.2 OPUS-RS (Rapid Static)

This variation of OPUS will compute accurate positions using 15 minutes of data or more. The methodology will be different than the one used in standard OPUS. OPUS-RS will do a simultaneous network solution. A maximum of 6 CORS sites could be used, although there is a restriction of a maximum radius of 200km from the rover station. The main reason for this restriction is the necessity of modeling the troposphere and ionosphere in order to reliably fix integer ambiguities for short data spans. The basic theory adapts ideas previously developed by Kashani et al. [2005].

7 CONCLUSIONS

Since 2002, NGS has provided the GPS community with OPUS processing, free of charge. OPUS procedures are, by now, well established and the popularity of the service continues to increase. However, NGS is expanding the service to include rapid static solutions requiring 15 minutes of data or more, and the capability to include solutions done by any GPS user that follows a limited number of restrictions in the IDB. Under long- term development there will be other variations of OPUS such as ”OPUS Projects” that will permit the user to submit simultaneous files from different stations. Then, OPUS will do a simultaneous adjustment of all data and provide coordinates for all points. The possibility of obtaining single frequency solutions is also in the early stages of investigation and mainly depends on the availablity of sophisticated ionospheric models. Finally, also under study, is an OPUS solution using only differential range (code) solutions capable of processing data from handheld GPS receivers. Clearly this implementation will be geared to the GIS community. All-in-all, NGS is not neglecting any sector of professionals depending on GPS for their day-to-day work and it is only a matter of time before services will be available to cover the large range of geodetic, surveying, and mapping applications that GPS is capable of enhancing.

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BIOGRAPHICAL NOTES

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