**GAGE GPS Data Analysis & Data Product Plan**

*21 August 2014*

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*Note: this document was written to be an updated version of Appendix D in the PBO Critical Design Review (CDR) document. This document is being released ahead of the fully updated CDR document in order to provide the most up to date information on GAGE GPS analysis and data product generation procedures. In most cases, the term "PBO" is synonymous with "GAGE" now that PBO network is operated by UNAVCO as part of the GAGE facility. Details about recent analysis methods, products, status and statistics are provided in the ACC's quarterly reports available from the UNAVCO website.*

## D.1 Introduction

GPS analysis for the Plate Boundary Observatory (PBO) is carried out in two phases. Analysis centers (ACs) at the Central Washington University (CWU) and New Mexico Institute of Mining and technology (NMT) process the GPS phase and pseudorange data to generate estimates of the coordinates of the GPS sites averaged over 24 hour periods. The Analysis Center Coordinator (ACC) at the Massachusetts Institute of Technology (MIT) combines the results from these analyses, produced in the SINEX format, to generate the final PBO station coordinate product. Associated with the generation of these products, files containing the statistics on the phase data and estimates of atmospheric delays are also generated. The site coordinate information is made available both in SINEX format, containing full variance covariance information, and as time series files. The time series results are generated in a North American fixed reference frame and in the ITRF 2008 no-net-rotation reference frame. The results from the daily position estimates are combined to generate long-term velocity estimates of the sites in both the North America fixed frame and ITRF2008. In generating these velocity results, offsets due to earthquakes and equipment changes, low-quality results due to snow, for example, are taken into account.

The philosophy in generating the daily position results is to include all results generated by the analysis centers. Even in cases where the daily position estimate is not likely to be correct, for example due to excess snow on the antenna, results are still retained in the time series and SINEX files. This procedure is used to allow users to reach their own conclusions concerning the quality of the data. By retaining the estimates uses are aware of the existence of the data at that time although in most cases the estimates would be discarded from normal processing. When velocity fields are generated, these bad data are eliminated so as not to corrupt the velocity estimates.

## D.2 Analysis models

The analysis methods used by the PBO analysis centers conform to the IERS 2010 conventions [IERS TN36, 2010]. Two different analysis programs are used to process the phase and range data collected by the PBO GPS receivers. The analysis group at CWU uses the GIPSY/OASIS-II processing system developed at the Jet Propulsion Laboratory. The analysis group at NMT uses the GAMIT/GLOBK software developed at the Massachusetts Institute of Technology. The processing specifications for each of the analysis centers are given at the end of this document.

The PBO analysis centers adhere to the IERS2010 conventions but there are some differences between the ACs that fall into the options allowed in the conventions.
In terms of IERS2010 conventions, the PBO analysis centers use the Vienna mapping function VMF1 for determining the mapping function. However, there are differences in the apriori atmospheric pressure model. NMT uses the pressure, mapped to the height of the sites from the VMF1 grid files while CWU uses a simple fixed mean-sea-level mapped to the height of the site. This difference is expected to generate height differences between the two analyses that depend on deviations of atmospheric pressure from a constant value. To be consistent with the IGS processing standards, atmospheric pressure and water loading signals are not applied during the processing. In general, IGS products are used for the processing, although there are some deviations to ensure the consistency of the products generated by CWU and NMT. For the NMT analysis, IGS final orbits are held fixed (rapid orbits are used for the rapid products). For the CWU analysis JPL final orbits and clocks are used for all recent processing to ensure scale compatibility with the IGS08 reference frame. The transition to the IGS08 frame occurred on Date 2011/04/17, day-of-year 107, GPS Week 1632 [Rebischung et al., 2012] and all data prior to this change have been reprocessed in the IGS08 frame. The specific issue here is that the clock estimates generated by the original IGS processing (using the ITRF 2005 scale and antenna models) implicitly impart a scale change to the point positioning results generated by CWU. This problem does not affect the NMT processing because a double difference method is used to eliminate the clocks from the solution.

The AC solutions are delivered in SINEX format for the geodetic parameter estimates and tabular files containing information about the root-mean-square (RMS) scatter and number of phase residuals by site for each day. The NMT RMS files also contain information on the elevation angle dependence for the phase residuals. The SINEX file submitted by the AC are directly copied to the UNAVCO archive and are designated as "loose" files. The contents of the RMS files submitted by the ACs are merged into a single file labeled with a .rms extent and sent to UNAVCO. These .rms files have a header that explains the contents of the file. An example of an .rms file from rapid solution is pbo18030.rapid_nam08.rms.

Format of the RMS file.

```
RMS File from  ../CWU_snx/cwu18030.20140727.a.rms ../NMT_snx/nmt18030.20140727.a.rms
Format Version : 1.1.0
Release Date   : 20140729120137
Start Field Description
Dot#            4-character identifier for a given station
PBO_#           Number 30-sec phase epochs in 24-hours for combined RMS calculation
PRMS            Root-mean-square (RMS) scatter of combined phase residuals, mm
CWU_#           Number 30-sec phase epochs in 24-hours for CWU RMS calculation
CRMS            Root-mean-square (RMS) scatter of CWU phase residuals, mm
NMT_#           Number 30-sec phase epochs in 24-hours for NMT or BSL (prior to Feb 2006)
RMS calculation
NRMS            Root-mean-square (RMS) scatter of NMT or BSL phase residuals, mm
A               Coefficient from model fit RMS^2(elev) = A^2 + B^2/sin(elev)^2 where elev
is elevation angle, mm
B               Coefficient from model fit, mm
GPSW            GPS Week for 24-hour processing day
D               GPS Day of week for 24-hour processing day
YYYYMMDD        Year, month, day of month for 24-hour processing day
End Field Description
*Dot#  PBO_#   PRMS    CWU_#   CRMS     NMT_#  NRMS        A      B GPSW D YYYYMMDD
 1NSU  22668    9.7    21140    8.5     24197   10.9     4.9    4.2 1803 0 20140727
 1ULM  22792    8.1    21030    7.0     24555    9.1     4.2    3.4 1803 0 20140727
 7ODM  22639    9.9    21010    9.4     24268   10.5     5.5    3.9 1803 0 20140727
 AB01  22657    6.4    20950    5.7     24365    7.1     3.0    2.7 1803 0 20140727
 AB02  22127    7.2    20190    5.9     24064    8.4     2.1    3.6 1803 0 20140727
…
 ZBW1  22739   12.8    21320   11.2     24158   14.3     6.1    5.5 1803 0 20140727
 ZDC1  22599   11.6    21400   10.2     23799   13.0     4.9    5.2 1803 0 20140727
 ZDV1  23263   11.8    21410   10.6     25117   13.1     5.8    4.7 1803 0 20140727
 ZKC1  22789   12.8    21110   11.0     24468   14.7     4.3    6.0 1803 0 20140727
 ZLA1  23850   12.8    22230   11.7     25471   14.0     8.2    4.8 1803 0 20140727
 ZME1  22512   12.2    20880   10.9     24145   13.6     6.5    5.0 1803 0 20140727
 ZMP1  22657   11.9    20880   10.2     24434   13.6     6.0    5.2 1803 0 20140727
 ZNY1  22610   10.6    21270    9.4     23950   11.7     5.8    4.3 1803 0 20140727
 ZSE1  22972   11.7    21710   11.3     24235   12.0     6.4    4.2 1803 0 20140727
 ZTL4  22242   10.9    20760    9.7     23724   12.2     5.6    4.7 1803 0 20140727
```

In these files, the A and B coefficients representing the elevation dependence, expressed by the equation in the file header, are supplied by NMT. The number of data points in the CWU column are multiplied by 10 to make the values 5-minute sampled values used to CWU consistent with the 30-second sampled values used by NMT. The PBO estimates are the averaged values between the NMT and CWU results weighted by the number of data listed.

The SINEX files supplied by the ACs are generated are generated differently. The NMT SINEX are delivered with weak constraints (100 meters) applied to the coordinates and are considered to be fiducial free solutions. These SINEX files have a full variance covariance matrix. The CWU solutions are from point positioning and the standard deviations of site coordinates are small (typically 1-3mm). The covariance matrix for these SINEX files has no site-to-site covariance values. In order to make these SINEX file fiducial free, we added to the block diagonal covariance matrix in the SINEX flies, a covariance matrix, which allows the system to rotate and translate so that we align them to different reference frame realizations. There no earth orientation parameter (EOP) estimates in the CWU SINEX files and so we do not attempt to estimate EOPs in the PBO analyses.

The procedures used to generate the daily PBO products are the same for all latency products. There are four different latencies in the PBO products (see section D.3). The rapid solution latency is typically 24-hours and is generated when the IGS rapid products become available. Rapid solutions are generated daily. The final analysis latency is 2-3 weeks and is generated with the IGS final orbit becomes available. These analyses are performed in 1-week batches. Two other analyses are performed with 12-week and 26-week latency and added to the final analysis sites whose data was not available at the time the final analysis was run. The long latency solutions are referred to supplemental and supplemental 6month solutions.

Two different schemes are used by the ACs for weighting the phase and range data and the sampling interval used in the estimation scheme. NMT uses an elevation angle dependent phase data sigma (see RMS file example above) with the values used for each station determined from the post-fit phase residuals. The pseudo-range are not directly used the geodetic parameter estimation in the NMT analysis. Phase measurements are sampled every 2 minutes in the estimator. CWU used a fixed phase sigma independent of the elevation angle and the RMS scatter of the phase data at individual sites. 5 minute phase measurement samples are used in the estimator. This difference in the noise models and sampling rates in the geodetic analysis results in the need to scale the variance covariance matrices from the SINEX files. The scale factors are determined such that the average values of the $\chi^2/f$, where f is the degrees of freedom, of the fits to the reference frame sites (typically 250 per day) are near unity. Fixed scale factors for all NMT and CWU solutions of 0.7 and 4.8, respectively, are used. When the two AC results are combined, these factors, applied to variances, are doubled so that the individual AC and combined PBO solutions have similar standard deviations for the geodetic parameter estimates.

The PBO individual AC and combined daily solutions are aligned to the PBO realization of the North American plate using 500-600 reference frame sites. A hierarchical list of sites is used based on grid with 150 km node spacing placed over PBO geographical region. In each grid cell a sorted list of sites in that cell is generated based on the process noise value associated with each site. During frame aligned only one site from each cell is used. In the current realization, up to 604 sites could be used with a typically number being about 530 sites. The loose frame solutions are rotated and translated to align to the North America reference frame. The heights are down weighted by a factor of 1000 in determining the reference frame transformation parameters. An IGS08 no-net-rotation (NNR) frame solution is also generated using similar algorithms but operating on the time series generated in the North America frame. This operation is done using the GAMIT/GLOBK program tscon. The hierarchical list of reference frame sites is given in All_PBO.stab.

The current North America reference frame, NAM08, is based on rotating IGS08 into the North America frame using the Euler pole from Altamimi et al. [2012]. The rotation vector used has rotation rates around the X Y and Z axes of 0.0275 -0.6752 -0.0729 mas/yr. This rotation vector corresponds to a rotation pole at longitude/latitude of -87.6655/-6.1542 degs, rotating with a rate of 0.1888 deg/Myr. The PBO reference frame is center of figure (as is ITRF2008). To generate results in a center of mass system, Altimimi et al., 2012 gives the translation rates as (Tx Ty Tz) = (0.41 0.22 0.41) mm/yr to be used. The initial frame is realized by aligning the PBO combined velocity solution to IGS08 rotated to North America using 19 IGS08 sites (KELY, STJO, SCH2, THU3, WES2, NRC1, GODE, ALGO, NLIB, CHUR, DUBO, FLIN, MDO1, PIE1, YELL, GOLD, DRAO, MKEA, BILI). The positions and velocities of the PBO sites generated from this solution are then used as the basis of the daily frame realization. The IGS08 coordinates used for the original position and velocity alignment is igs08_noam.apr. Time series fitting to the NAM08 aligned time series, including earthquake offsets, post-seismic log fits, and antenna discontinuity offsets and annual signal are used to generate the final NAM08 reference frame apriori coordinate file. The current version is All_PBO_nam08.aprfor NAM08 and All_PBO_igs08.apr for IGS08. In future reference frame apriori coordinate files, the annual periodic signals are likely to be removed since these seem to generate artifacts in the seasonal signals seen at PBO sites. Discontinuities included in the analyses are given in several GLOBK earthquake/rename files. In GLOBK, sites are given 8-character site names. The first 4-characters are given the standard 4-character site codes of the PBO sites. A standard site name would have GPS as the other 4 characters. Sites affected by earthquakes have the last 2 characters of their name (PS by default) to a 2-character code associated with the earthquake. For PBO these codes are most 2-digit numeric values incremented with each earthquake. For large earthquakes, descriptive 2-character codes are often assigned such a PA for the 2005 Parkfield event. The *EQ_DEF* lines in the earthquake files give the assigned code. For antenna offsets, the 6$^{th}$ character in the name is changed starting with 2 and numerically progressing into the capital letters except G and X (XPS and XCL names denote sites to be removed for the analysis). Antenna offsets are included when ever an antenna is changed at the site. Some offsets are observed in the time and their origin is often not known. (In some cases, they are due to the onset of damage at a time that can only be determined by examining the time series. The current PBO earthquake file is All_PBO_eqs.eq, antenna offsets due antenna changes file is All_PBO_ants.eq and the offsets due to unknown reasons (speculations are included in the comments in the file) is All_PBO_unkn.eq.

**D.3 Velocity field generation**

PBO velocity fields are generated by two different methods on two different time scales. On an annual basis, velocity fields are generated using a full SINEX combination. These annual solutions use the discontinuity files given above and process noise models for the sites that account for the temporal correlations in the time series. The process noise models, in the form of random walk time-step variances are given in All_PBO.rw. A list of sites to be used in thee solutions is given in All_PBO.use based on the process noise levels at the sites. Sites which have process noise values greater than 2.0 mm$^2$/yr are not included in this velocity solution so that they do not contaminate nearby sites. The process noise statistics are generated from the time series using the GAMIT/GLOBK script sh_gen_stats based on tsfit fits to the time series with the realistic sigma algorithm used to account for correlated noise. The tsfit solutions also generates a lists of site position estimates not to be used in the velocity solution because they are outliers (either due to bad analyses, antenna failures or snow on antennas). The current list of edited site position estimates is given in All_PBO_edits.eq. These edits can by AC or for both ACs. Because of the long run time of these SINEX velocity solutions, they are currently run as 7 separate combinations with solutions using 1 day per week on each day of the week. These 14 runs, 7 for CWU and 7 for NMT, can be run parallel and then combined at the end. Each of the 7 solutions is given a 1/7 weight variance to account for the correlated noise in the solutions when the 7 days of solution are combined. Once the velocity solution is completed, the velocity estimates at sites with multiple names are made equal using the equate command in the GAMIT/GLOBK module glorg. IGS08 velocity fields can be generated from the final combination by changing the reference frame alignment with glorg.

The August 2014, and later PBO velocity solutions will be generated differently due to long runs times, even with the decimation, needed to combine the 1800 sites in the solution between 1996 and 2014 (with renames due to earthquakes and antenna changes, there are over 4000 site names in the final solution). The next generation of solutions will created by running the velocity combinations on sub-networks of sites and the combining the sub-networks together. This approach should be much faster then the current one.

The other type of velocity solution generated uses the time series directly and this approach is much faster. These solutions are generated monthly and use the same discontinuity and earthquake files as the full velocity solutions. The process noise models and data editing are created in these solutions. These velocity fields are called snapshot velocity fields. All sites are included in these files because there are no interactions between the sites.

### D.4 Products generated by Analysis Center Coordinator

The ACC uses the Level 2a SINEX files from each Analysis Center to produce a series of combined Level 2b GPS data products, in accordance with standards laid out above.

(a) Daily rapid solutions
Merged SINEX files based on each day's rapid SINEX files. These merged files contain network solutions that are loosely constrained and constrained to a standard reference frame as described in D.2. Additionally, ASCII time series, containing data not yet in the final solutions (see below), are created from the merged and constrained SINEX files. The SINEX alignments are made to the NAM08 reference frame. Normally, the rapid time series files will contain 7-14 days of results depending on the generation of the finals solution. Daily reports are generated that compare the results between the two AC solutions, report metadata errors, and

note sites with deviations from the apriori motions of the sites. The IGS08 time series are generated by aligning the NAM08 time series files to the IGS08 no-net-rotation system.

(b) “Final” solutions
Merged SINEX files based on each day’s “final” SINEX files. These solutions are generated with IGS final orbit products for NMT and JPL final orbit and clock products for CWU. These merged files contain network solutions that are constrained to a standard North America fixed reference frame. ASCII time series will be derived from this combined solution and these time series files contain the times series for all data processed to date. These products are generated in 7-day batches based on GPS weeks and will become available after the weekly releases of the IGS final orbits. Reports are generated from each day of data in the week and contain the same information as the rapid processing described above. Time series in North America fixed (NAM08) and the International Terrestrial Frame (ITRF2008 as realized through IGb08 are generated. SINEX files in fiducial free (loose) and NAM08 are generated.

(c) "Supplemental” solutions
SINEX files generated by merging the solution files from the corresponding final solution with supplemental solutions that contain sites not in the original final solution and a small number of overlap sites to allow alignment of the reference frame. ASCII time series files, merged with the final time series files, are generated from these supplemental analyses. The supplemental analyses are run with 12-week and 26-week latencies (SUPPL and SUPP6 labels where the 6 is for 6 months).

(d) Velocity solutions
The full velocity solutions derived from the combined SINEX files annually, and these files are updated using fit to the time series on a monthly basis. The annual velocity solutions are provided in both ASCII and SINEX formats in North America and in IGS08 reference frames. The velocity field solutions incorporate estimates of offsets from antenna changes, equipment problems (such as broken radomes), and earthquakes. For earthquakes with large post-seismic deformations, time dependent models are estimated, in the form of log functions with earthquake dependent time constants, so that the velocity estimates will not be greatly affected by the earthquake. Monthly velocity estimates are also generated based on time series analysis (direct fitting to time series as opposed to the (much more time consuming) rigorous combination of SINEX files) in North America fixed and IGS08 frames. These monthly velocity field estimates are referred to as snapshot velocity fields.

(e) Coseismic offsets for significant events
The ACC generates “rapid” and “final” offset estimates for events that result in station position displacements beyond an agreed upon threshold (currently 1mm),

for stations within the footprint of all processing groups. All offsets will be archived (and made available for download) in a centralized place by the ACC and UNAVCO.

These estimates are made available rapidly after large earthquakes with the initial estimates based on the difference between position estimates two days before and after the day of the earthquake (thus a 3-day latency). These estimates are updated at the time when the final and supplement runs are submitted by the ACs. These later runs could contain more sites than the initial rapid solutions. During the annual velocity field analyses, the need for postseismic signal modeling will be assessed and incorporated in the velocity solution estimates.

An empirical algorithm based on fits to coseismic models and GPS estimates is used to make a preliminary assessment of the likely magnitude of offsets from an earthquake. This algorithm is embedded in the GAMIT/GLOBK script sh_makeeqdef which creates an GLOBK earthquake definition file that can be used (after name modification) in GLOBK and the time series fitting tools tsfit and tsview. Each candidate earthquake is examined in tsview and an assessment made of wether the event contributed a significant coseismic offset. In some cases, this assessment can be difficult due to missing data and snow and/or ice on antennas (especially for some Alaska and volcanic sites). If the event is deemed significant is added to the cumulative PBO earthquake definition file with, in most cases, a sequential 2-digit number assigned to the earthquake. For large events, a 2-charater code is often assigned (e.g., PA for the 2010 Parkfield earthquake.) Initially, the NEIC catalog (http://neic.usgs.gov/) used to query earthquake locations and magnitudes, but upgrades to the their system in 2013 made use of it not possible and now the ISC bulletins are used (http://www.isc.ac.uk). The algorithm used predicts the distance from the epicenter that 1 mm coseismic displacement could happen and the magnitude of the possible of offsets as a function of distance from the epicenter based on the magnitude of the earthquake in the catalog. Since this is an approximate algorithm, the magnitude in the catalog, independent of its type, is used.

In most case, two-days before and after the earthquake, excluding the day of the earthquake, are used to compute the offsets. In some cases when data near the earthquake are missing, an extended number of days will be used. This feature is sometimes needed for sites with low telemetry rates.

### D.5 GLOBK documentation

The GLOBK processing scripts and control files are given in PBO_ACC_export.tar file. The PBO_export_README.txt file explains how to use the files contained in the tar file. The control and tables directories included the export tar are included here as well. (The export tar file is large because it contains example data sets as well). The contents of this file are given here.

Notes on use of PBO processing scripts

These scripts assume that GAMIT/GLOBK is installed and the standard gg link exists.  The scripts included here are the operational scripts.  These scripts can be used to reference to an ftp area where subdirectories NMT and CWU would contain SINEX and RMS files generated by the PBO Acs.  For most users, the simpler method is to put the SINEX and RMS files in the subdirectories NMT_snx and CWU_snx.  The RMS files are not needed to generate position time-series but some of the summary scripts will report errors if the RMS files do not exist (these errors can be ignored if phase RMS values are not of interest).

A small number of SINEX files generated by the AC have been saved in the NMT_snx and CWU_snx files for testing.  These files are for 2012 12 31 (all solutions) and 2013 01 01 rapid solution.  This latter file is included because the sh_rapid_ts shell script that generates rapid time series files will only generate values for dates that are after the last final orbit solution processed.  The scripts also contain features unlikely to be used by other users such as the ldm option which queues solution to LDM to be transferred to UNAVCO.

To test the solutions use the following commands to be executed in the export/control directory.

```
csh PBO_final.cmd -d 2012 366 -m `whoami` -clear > & ! FIN_12366.out
sh_final_ts -w 1721
csh PBO_rapid.cmd -d 2013 6 -m `whoami` -clear -ts > & !
RAP_13006.out
```

Other solutions that can run are

```
csh PBO_suppl.cmd -d 2012 366 -m `whoami` -clear >&! SUP_12366.out
csh PBO_supp6.cmd -d 2012 366 -m `whoami` -clear >&! SU6_12366.out
csh PBO_repro.cmd -d 2012 366 -m `whoami` -clear >&! REP_12366.out
```

After each of these runs, the corresponding sh_<type>_ts script is used to generate the time-series files.

Notes on above solutions:
Since final, suppl, supp6 and repro solutions are usually processed one week batches, the time series files are created after the last day of the week has been processed and so above we explicitly show the use the time series generation script/

When using these scripts, you should regularly update the earth orientation parameter (EOP) a priori values using GAMIT script sh_update_eop.
In the export/tables directory use:

```
sh_update_eop -ser usno
```

Information after station meta data should be kept update by down loading station.info from the GAMIT/GLOBK ftp site into the export/tables directory.  In general, the tables directory for your GAMIT/GLOBK installation should be updated regularly.  (The station.info file in export/control could be linked to ~/gg/tables/station.info to ensure it is kept up to date.

Meta data errors are reported in the processing scripts and the example data given show how changes in the antenna phase center models can effect the results. (Models for two antennas were changed between the original finals processing and the values used now).

## References

Altamimi, Z., L. Métivier, and X. Collilieux (2012), ITRF2008 plate motion model, J. Geophys. Res., 117, B07402, doi:10.1029/2011JB008930.

IERS TN36 (2010) TN36.html

Rebischung, P, J. Griffiths, J. Ray, R. Schmid, X. Collilieux and B. Garayt, (2012), IGS08: the IGS realization of ITRF2008, *GPS Solutions 16*:483-494 DOI 10.1007/s10291-011-0248-2
http://download.springer.com/static/pdf/648/art%253A10.1007%252Fs10291-011-0248-2.pdf?auth66=1384569269_41588ddafabceb649e99d1482132d72e&ext=.pdf

## Central Washington University Processing Specifications

```
|==========================================================================|
|                                                                          |
|                                                                          |
|                     PLATE BOUNDARY OBSERVATORY (PBO)                     |
|                                                                          |
|                    CWU Analysis Center Strategy Summary                  |
|                                                                          |
|                                                                          |
|==========================================================================|
|ANALYSIS CENTER     | Central Washington University (CWU)                 |
|                    | Geodesy Lab & PANGA Facility                        |
|                    | 400 East University Way                             |
|                    | Ellensburg, WA 98926                                |
|                    | USA                                                 |
|                    | Fax: +1 509 963 1109                                |
|                    | Data Archive:                                       |
|                    |    ftp://sideshow.jpl.nasa.gov/pub/JPL_GPS_Products |
|                    |    ftp://ftp.panga.cwu.edu/pub/pbo_ac               |
|--------------------------------------------------------------------------|
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|                    |   Phone:  +1-509-963-2705                           |
|                    |                                                     |
|                    | M.S. Marcelo Santillan                              |
|                    |   E-mail: marcelo (at) geology.cwu.edu              |
|                    |   Phone:  +1-509-963-1107                           |
|                    |                                                     |
|--------------------------------------------------------------------------|
|SOFTWARE USED       | GIPSY/OASIS-II Version 6.1.2 developed at JPL       |
|                    | GOAT (GIPSY OASIS Toolkit) developed at CWU         |
|--------------------------------------------------------------------------|
```

| | |
|---|---|
| List of JPL's analysis products<br><br>Rapid Products generated daily in fiducial frame | YYYY-MM-DD.pos GPS orbits for all satellites<br>YYYY-MM-DD.tdp Satellite clocks + yaw rates<br>YYYY-MM-DD.eo Earth orientation parameters<br>YYYY-MM-DD.shad Shadow events<br>YYYY-MM-DD.ant Receiver/Transmitter antenna calibration used<br>YYYY-MM-DD.frame Reference frame for provied orbits<br>YYYY-MM-DD.wlpb Global set of wide-lane biases used for bias fixing (PPP-AR) |
| Final Products generated weekly in non-fiducial frame<br><br>YYYY : 4 digit year<br>MM : 2 digit month<br>DD : 2 digit day | YYYY-MM-DD_nf.pos GPS orbits for all satellites<br>YYYY-MM-DD_nf.tdp Satellite clocks + yaw rates<br>YYYY-MM-DD_nf.eo Earth orientation parameters<br>YYYY-MM-DD.shad Shadow events<br>YYYY-MM-DD.ant Receiver/Transmitter antenna calibration used<br>YYYY-MM-DD.frame Reference frame for provided orbits<br>YYYY-MM-DD.x 7 parameter Helmert's transform from fiducial frame to the frame in .frame file<br>YYYY-MM-DD_nf.wlpb Global set of wide-lane biases used for bias fixing (PPP-AR) |
| PREPARATION DATE | June 26, 2013 |
| MODIFICATION DATES | |
| EFFECTIVE DATE FOR DATA ANALYSIS | |

| MEASUREMENT MODELS | |
|---|---|
| Preprocessing | Carrier Phase: Decimated to 5 minutes<br>Pseudorange: Decimated to 5 minutes<br>Cycle slip detection |
| Basic Observable | Undifferenced ionosphere-free carrier phase, LC<br>Undifferenced ionosphere-free pseudorange, PC<br>Elevation angle cutoff: 15 degrees<br>Sampling rate: 5 minutes<br>Data weight, LC: 1 cm<br>Data weight, PC: 1 m |
| Modeled observable | Undifferenced LC and PC combinations<br>CA-P1 biases from CODE applied |
| RHC phase rotation corr. | Applied |
| Marker -> antenna ARP eccentricity | dN, dE, dU eccentricities from CWU sinex file applied to compute station marker coordinates |
| Ground antenna phase center cal. | PCV model from igs08_wwww.atx applied<br>Receiver antenna and radome types from CWU sinex file |
| Troposphere | A priori model: Dry delay<br>1.013 * 2.27 * exp(-.000116 * h) |

| | |
|---|---|
| | with h in meters.<br>Wet delay 10 cm<br>Mapping Function: Vienna Mapping Function (VMF1) in weekly runs<br>Niell Mapping Function (NIELL) in daily runs<br>Estimation: Zenith delay and horizontal gradients |
| Ionosphere | 1st order effect: Removed by LC and PC combinations<br>2nd order effect: Not modeled |
| Plate motions | |
| Tidal | Solid earth tide: IERS 2010 Conventions |
| | Permanent tide: NOT removed from model, so NOT in estimated site coordinates |
| | Pole tide: IERS 2010 Conventions |
| | Ocean Tide Loading corrections:<br>FES2004<br>Computed by OLMPP by H G Scherneck<br>Onsala Space Observatory |
| | Ocean Pole Tide Loading: Not applied |
| Non-tidal loading | Atmospheric Pressure: Not applied |
| | Ocean Bottom Pressure: Not applied |
| | Surface Hydrology: Not applied |
| | Other Effects: None applied |
| Earth Orientation Parameter (EOP) Model | IERS 2010 Conventions for diurnal, semidiurnal, and long period tidal effects on polar motion and UT1 |
| Satellite center of mass correction | Phase centers offsets from igs08_wwww.atx applied |
| Satellite antenna phase variations | PCV model w.r.t. phase center from igs08_www.atx applied |
| Relativistic corrections | Not applied |
| GPS Attitude model | GYM95 nominal yaw rate model from Bar-Sever (1996) and yaw rates for Block II satellites |

| ESTIMATED PARAMETERS (APRIORI VALUES & SIGMAS) | |
|---|---|
| Adjustment | Stochastic Kalman filter/smoother implemented as square root information filter with smoother |
| Station coordinates | Daily Point Positioning estimates with rapid orbits<br>Weekly free-network estimates to get weekly, supplemental 12 weeks, and supplemental 6 months with finals |
| Satellite clock | Not estimated |

| | |
|---|---|
| Receiver clock | Estimate every 5 minutes |
| Orbital parameters | Not estimated |
| GPS Attitude parameters | Not estimated |
| Troposphere | Zenith delay: random walk 5.0d-8 km/sqrt(sec)<br>Horizontal delay gradients: random walk 5.0e-9 km/sqrt(sec) |
| | Mapping function: VMF1 (finals) NIELL (rapids) |
| Ionosphere | 1st order effects removed by LC and PC combinations and 2nd order effects not modeled, |
| Ambiguity | Ambiguities resolved in weekly run with final orbits |

## REFERENCE FRAMES

| | |
|---|---|
| Terrestrial | IGS08 station coordinates and velocities |

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## NMT analysis specifications

PLATE BOUNDARY OBSERVATORY
NMT Processing Strategy Summary

| | |
|---|---|
| Analysis Center | New Mexico Tech (NMT)<br><br>Dept Earth & Environmental Sciences<br>801 Leroy Place<br>New Mexico Institute of Mining and Technology<br>Socorro, NM 87801<br>Phone: ++ 1 575 835 6930<br>Fax: ++ 1 575 835 6436 |
| Contact Person(s) | Mark Murray e-mail: murray@nmt.edu<br>phone : ++ 1 575 835 6930 |
| Software Used | GAMIT v. 10.5, GLOBK v. 10.5, developed at MIT/SIO |
| Preparation Date | March 5, 2014 |
| Modification Dates | New |
| Effective Date for Data Analysis | January 5, 2014 |

| MEASUREMENT MODELS | |
|---|---|
| Observable | Doubly differenced, ionosphere-free combination of L1 and L2 carrier phases. Pseudoranges are used only to obtain receiver clock offsets and in ambiguity resolution. |
| Data weighting | Sigma on doubly difference LC phase: Site and elevation dependent based on iterated analysis.<br>Cleaning at 30-second rate.<br>Sampling rate: 2 minutes<br>Elevation angle cutoff : 10 degrees |
| Data Editing | Cycles slips detected and fixed.<br>Unresolved cycle slips estimated in solution.<br>Postfit editing using 4 times RMS deletion. |
| RHC phase rotation corr. | Phase polarization effects applied (Wu et al, 1993) |

| | |
|---|---|
| Ground antenna phase center calibrations | Elevation- and azimuth-dependent phase center corrections are applied according to the model IGS08. The corrections are given relative to the Dorne Margolin T antenna. |
| Troposphere | Atmospheric mapping functions and hydrostatic zenith delays from VMF1 numerical model (Boehm et al., 2006b) 2-hour piecewise linear function estimated, 2 NS and EW gradient per day. |
| | Met data input: VMF1 global numerical model (Boehm et al., 2006b) |
| | Mapping functions: VMF1 (Boehm et al., 2006b) |
| Ionosphere | Not modeled (ionosphere eliminated by forming the ionosphere-free linear combination of L1 and L2). |
| Plate motions | ITRF2008 velocities |
| Tidal displacements | Solid earth and tidal displacement:<br>constant Love number tides<br>frequency dependent radial tide (K1) |
| | Pole tide: Applied to Mean IERS pole position |
| | Ocean loading: FES2004 (Lyard et al., 2006) |
| Atmospheric loading | Not applied |
| Earth orientation | IERS Bulletin A plus diurnal and semidiurnal variations in x,y, and UT1 models (EOP) R. Ray [1995], IERS Tech. Note 21 [1996] |
| Satellite center of mass correction | Block I x,y,z: 0.2100, 0.0000, 0.8540 m |
| | Block II/IIA x,y,z: 0.2790, 0.0000, 0.9519 m |
| | Block IIRA/IIRB x,y,z: -0.0031, -0.0012, 0.0000 m |
| | Block IIRM x,y,z: 0.0000, 0.0000, 0.0000 m |
| | Block IIF x,y,z: 0.3940, 0.0000, 1.6000 m |
| Satellite phase center calibrat | Not applied |
| Relativity corrections | Relativistic corrections applied |
| GPS attitude model | Yaw computed using model of Bar-Sever (1996), using nominal rates or estimates supplied by JPL |

| ORBIT MODELS | |
|---|---|
| Geopotential | EGM08 degree and order 9 (Pavlis et al., 2012) |
| | GM = 398600.4415 km**3/sec**2 |
| | AE = 6378.1363 km |
| Third-body | Sun and Moon as point masses |

| | |
|---|---|
| | Ephemeris: CfA PEP NBODY 740 |
| | GMsun = 132712440000 km**3/sec**2 |
| | GMmoon = 4902.7989 km**3/sec**2 |
| Solar radiation pressure | A priori: nominal block-dependent constant direct acceleration; corrections to direct, y-axis, and B-axis constant and once-per-rev terms estimated (Beutler et al., 1994; Springer et al. 1998) |
| | Earth shadow model: umbra and penumbra |
| | Earth's albedo: not applied |
| | Satellite attitude model not applied |
| Tidal forces | Solid earth tides: frequency independent Love number K2= 0.300 |
| | Ocean tides: None |
| Relativity | Applied (IERS 1996, Chapter 11, Eqn.1) |
| Numerical Integration | Adams-Moulton fixed-step, 11-pt predictor-corrector with Nordsieck variable-step starting procedure (see Ash, 1972 and references therein) |
| | Integration step-size: 75 s; tabular interval: 900 s |
| | Arc length: 24 hours |

| ESTIMATED PARAMETERS (A PRIORI VALUES & SIGMAS) | |
|---|---|
| Adjustment | Weighted least squares plus Kalman filter |
| Station coordinates | ~40 networks of ~45 stations per network. 2-3 common sites between networks. Weak constraints applied to site coordinates. |
| Satellite clocks bias | Initial values from linear fit to Broadcast emphemeris. Values estimated during data cleaning. |
| Receiver clock bias | Time estimated from pseudoranges. |
| Orbital parameters | Initial Position and Velocity (IC) plus 9 radiation-pressure terms: constant and sin/cos once-per-rev terms for a direct,y-axis, and b-axis acceleration. ICs estimated each day. Radiation parameters treated as random walk with process noise based on independent daily estimates. ICs fixed to IGS Final orbit values. |
| Troposphere | Piece-wise linear function in zenith delay estimated once per 2-hr for each station constrained by a random-walk process to 20mm/sqrt(hr); one N-S and one E-W gradient parameter per day for each station, constrained to 10 mm at 10 deg elevation angle |
| Ionospheric correction | Not estimated (first-order effect eliminated by linear combination of L1 and L2 phase) |

| | |
|---|---|
| Ambiguity | Resolution attempted for all baselines but resolving Melbourne-Webena Widelines for L2-L1 using pseudo-ranges with differential code biases applied, and then L1 from geodetic solution using ionosperic free observable. |
| Earth Orient. Parameters (EOP) | Pole X/Y and their rates, and UT1 rate estimated once per day. |
| GPS attitude model | Not estimated |

| REFERENCE FRAMES | | |
|---|---|---|
| Inertial | Geocentric; mean equator and equinox of 2000 Jan 1 at 12:00 (J2000.0) | |
| Terrestrial | ITRF2008, No constrained sites coordinates. | |
| Interconnection | Precession: IAU 1976 | |
| | Nutation: IAU 2000 | |

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