GOP AC's development for the Ultra-rapid orbit product

Jan Douša (jan.dousa@pecny.cz) Geodetic Observatory Pecný of the Research Institute of Geodesy, Topography and Cartography

Introduction

Since 2002, the Geodetic Observatory Pecný (GOP) has been providing ultra-rapid precise orbits. The GOP contributes to IGS from January 2004. Since that time, we have improved the solution in many aspects. During 2006, the improvements concerned mainly the pre-processing strategy, which plays a crucial role in the near real-time analysis aimed for the orbit determination, and prediction especially. Improving and tuning the orbit model at GOP and progress in assigning the accuracy code has been started in 2007 and is not definitely finished. While the GOP results are already very good in nominal situations, we further focus to improve the solution even during the specific periods (satellite maintenance, Block IIA eclipsing satellites, etc).

GOP processing background

GOP strategy is based on 6 hour of data processing which ends up with normal equations (NEQs). Using 6-hour update cycle, there is no redundancy in data processing. Saved NEQs contain only the short orbit arcs (6h). During the 6h iterative pre-processing stage, an intermediate orbit arcs (24h) are combined. The 6h pre-processing consists of the receiver clock synchronization, cycle-slip detection, ambiguity setup, residuals checking with outlier rejection, ionosphere estimation, ambiguity resolution and reference frame consistency checking with coordinate estimation. At the end, the final orbit solution is combined using the last 24 6-hour normal equations, thus a fitted 3-day arc is generated for stable 24h orbit prediction. The strategy is very efficient, but it strongly depends on the quality of consecutive six-hour analysis.

Network and data

Hourly data, with a good global coverage, is a crucial need for the precise near real-time orbit determination. The GOP processing strategy strongly depends on the near real-time data quality of the last 6 hours. The older data are no more relevant for our processing. Unfortunately, there are still problems to get the data for all the GPS satellites, e.g. for the satellites marked temporarily or permanently 'unhealthy'. Fig 1 shows a lack of data in 6-hour intervals. The figure also clearly demonstrates data volume oscillation in short windows due to unhomogenious station global coverage.

We revised GOP processing network with respect to the following criterions: 1) hourly data - quality, quantity and latency 2) global coverage 3) satellite tracking capability (!) 4) reference frame station 5) long-term stabilility and 6) GLONASS data (for the product extention).

To speed up the data as well as to possibly exploit an alternative (primary) sources, we implemented and tested the support of the real-time data storage using the RTIGSA (Archiver) and the BKG Ntrip Client (BNC) clients.

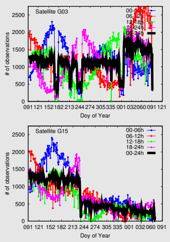

Fig. 1: *Data volume oscillation in 6-hour windows and the lack of data from G03 and G15 when marked unhealthy*

Ambiguities resolved

Wide-lane and narrow-lane ambiguity resolution in our six-hour pre-processing interval has been applied since March 2006. All the baselines with good code observables are solved for ambiguities at L6 and L3 linear combinations. Remaining baselines up to 1500 km are solved for ambiguities at L5 and L3 linear combinations. In average 75% of all ambiguities are resolved in 6-hour data window. The near real-time ionosphere product is also generated to support the ambiguity resolution if necessary. The station coordinates (longitude) has been about twice improved and the satellite orbits (especially the along-track component) and ERP parameters by a factor of 2-3.

Datum definition

All the IGS sites defining IGS05 and available in near real-time are a priori set as fiducial today. However, in every updated solution they are iteratively selected for the consistency with IGS05 reference frame. The NNR+NNT solution is then provided for constraining the IGS05 datum for all the coordinate estimation, which are later 'fixed' in the final orbit determination.

Processing efficiency optimized

The processing approach was optimized in 2006 in four steps: 1) 6-hour session setup and iterative strategy for pre-processing, 2) Bernese setup, 3) cluster setup for extensive parallel processing and 4) source-code efficiency protected.

Summary of the parallel processing, session length and source-code optimization is given in Table 1

Processing intrv.	Analysis time	Disk usage	Remarks
24 hours (1)	54 min	40 MB	cluster optimization
12 hours (1)	36 min	30 MB	cluster optimization
6 hours (0)	33 min	24 MB	no cluster optimization
6 hours (1)	30 min	24 MB	cluster optimization
6 hours (2)	24 min	24 MB	source-code + clust.optimiz.

Tab. 1: *Processing optimization for efficiency and disk usage*

Orbit modelling - specific satellite problems

The combination of normal equations for the long-arc orbits does not simply end always in better orbits. In case of satellite manoeuver (or even during other maintenances or eclipsing periods) the long-arc is under-parametrized and the entire solution is corrupted.

We have developed two techniques for operational combination of short-arc NEQ-based orbits into the combined long-arc multi-NEQ orbits. The first uses the iterative comparison of 6h (12h) orbit arcs with the final orbits over 3 days and if necessary the arc-splitting (or additional stochastic parameterization) can be completed for a specific satellite between two consecutive NEQs. Such technique is utilized in our final 3-day orbit combination, which is shown in Fig 2.

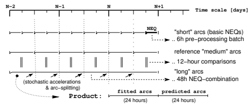

Fig. 2: *Scheme of the short arcs combination into the final long-arc and possible orbit model tuning.*

The second strategy is even more careful, but also more time-consuming. The a posteriori RMS for the solution and for the specific orbit parameters are checked using iterative long-arc combination. This strategy is applied during the updated intermediate orbits (24h) within the pre-processing stage.

The satellite manoeuvers are generally identified from 1) broadcast navigation messages 2) the single point positioning or 3) the tripple-dfference solution.

Our improved solution uses the weighting scheme for the specific satellites. These satellites are not anymore excluded from the analysis and all the pre-processing steps (residual checking, outlier rejection, ambiguity resolution, etc.) are not affected by the event. Satellite can be possibly excluded in the product, but since 2008 we do not exclude any satellite, but we assign a relevant accuracy code. However, sometimes the satellite is not in the product due to completely missing data in 6h analysis.

Accuracy codes

Besides the quality of the orbit prediction, relevant meassure of the product uncertainty should be assigned. So far we support only the satellite specific accuracy code in the SP3c-header, which is valid for both 24h fitted and 24h predicted product portion. However, we have significantly improved the quality measure during last years. We take into account different sources of information to assign the final accuracy code: the formal RMS of argument of latitude (dominant in orbit model), the consistency with respect to the previous GOU or IGU (predicted) product, the consistency of short-arcs versus long-arc orbits, eclipsing periods of the satellites. We also significantly encrease the accuracy code if many data is missing, too large RMS of argument of latitude element or when satellite is in the maintenance.

Optimizing the orbit model in GOP

For a long time, the extended orbit model, ECOM (Beutler et al. 1994), has been implemented in the Bernese GPS software (Dach et al. 2006) as well as the possibility of setting the stochastic pulses at any epoch. For the precise orbit prediction, the principal part of the ultra-rapid product, we would prefer to use only the deterministic orbit model. While the stochastic parameters improve the orbit fitting (demonstrated also in Fig 4), only if they result in better RPR and Keplerian parameter estimates, we can expect the improvement in the prediction too. We have provided a parallel test for tuning the deterministic and stochastic orbit model in GOP, which, in principal, follows the tests carried out by Springer et al (1999). Different strategies were in consistent way combined into the long-arcs and all resulted parameters were examined. Fig 4 shows the time-series of the orbits (fit, 12h-pred, 24-pred) compared to IGS rapid orbits. The ERP parameters were compared to IGS finals (Fig 3). Coordinates were examined by the repeatabilities. The radiation pressure parameters (RPR) and the stochastic pulses were displayed for investigating their performance, (Figs 6, 5).

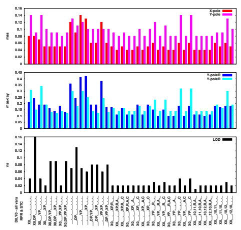

Fig. 3: *ERP estimated in different variants*

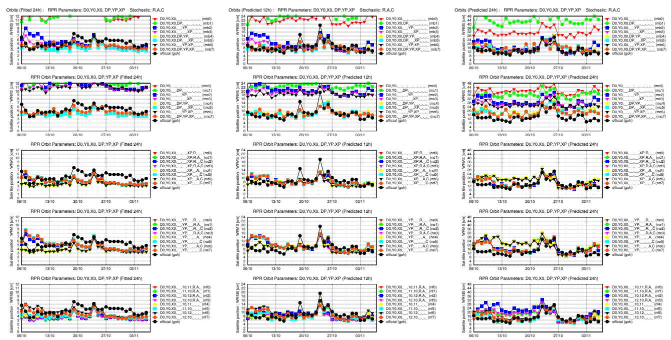

Fig. 4: *Testing variants of tuning deterministic and stochastic orbit models*

In case of a single satellite modeling problem we usually split the long-arc at relevant epoch(s) into two or more arcs during the 3-day final NEQ combination. So far we set up all the parameters of the deterministic model for a new arc. Because there is no reason why to change the RPRs, we further modified the software to use the stacking of RPRs regardless the setting up a new Keplerian element set.

Since December 2007, we have included the stochastic pulses for the eclipsing satellites into the orbit model. Stochastics parameters are set in radial, along-track and cross-track directions always in mid of 6 hour processing interval in which the eclipsing period mainly occures for a specific satellite. Usually, the stochastic pulses are prepared for the long-arc combination every 12 hours. So far the stochastic parameters are passive in our official solutions and we are still extensively testing their impact for the orbit prediction and especially for improving the problematic eclipsing periods of the old-type Block IIA satellites.

Though we achieve better orbits (1-2cm) in fitting portion of the ultra-rapid product, we haven't proved yet the improvements for the prediction, but some slightly degradation. Within the tests we identified also the problem of weak estimation of the last stochastic pulses in our solution, see Fig 5, which is caused by a few data after the pulse was setup. Thus we implemented the constrains for the stochastic parameters close to the end of the data fitting, otherwise it negatively affects the predictions.

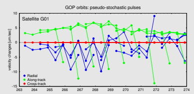

Fig. 5: *Stochastic pulses in radial and along-track direction*

In general, we proved all the results by Springer et al. (1999), concerning LOD degrades when D periodic terms are used, the best achived quality of using D0+Y0+X0+XP parameters + stochastic pulses in radial and along-track. We noticed a strong correlation between DP and X0, YP and XP parameters (see Fig 6). For the best orbits, in addition to D0,Y0, the estimation of X0×DP and YP×XP are necessary. Applying together unconstrained X0+DP or YP+XP is not recommended if only 3-day arc is aplied. We would like to focus for potential impact on the Block IIA eclipsing satellites.

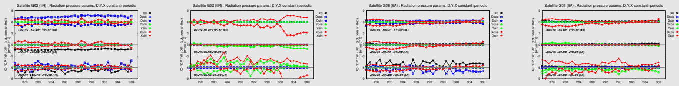

Fig. 6: *Correlation of the X0 and DP, YP and XP radiation pressure parameters for satellites G02 (IIR-B) and G08 (IIA)*

Evaluation of the GOP ultra-rapid product

A number of various developments in the GOP ultra-rapid orbits clearly lead to the improvements of all the estimated parameters during 2006-2008. Figs 7, 8 demonstrates the progress in the time-series of the orbit accuracy and the ERP parameters. Many changes were implemented especially during 2006, when pre-processing strategy was significatly improved for 6-hour data interval (ambiguity resolution, the satellite problem handling etc). The previous and actual products were tested in parallel during 2006, Tab 2. Another significant improvement has been initiated in 2007-2008 when we have focused on the orbit model tuning. We still expect some possible improvements in the model tuning for the different conditions. We will activate stochastic pulses if finally being convinced they do not degrade the prediction (besides improving fitting).

In general, the fitted as well as predicted orbits were improved by the factor of 2, the ERP parameters approx by the factor of 2-3. The periodic signal in the LOD and systematic error in Y-pole in GOP solution until 2006 were removed. They were caused by the phase shift during improper conversion into the IERS format. The accuracy code are much relevant today, even some more improvements are intended.

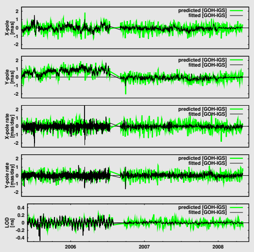

Fig. 7: *Improvements in the GOU ERP parameters during 2006-2008*

Fitted / predicted	Orbits [cm]	Sat-clks [ns]	X-pol [mas]	Y-pol [mas]	Xp-rate [mas/day]	Yp-rate [mas/day]	LOD [ns]
GOP bef2006	12	-	0.3	0.9	0.1	0.4	0.07
	24	-	0.5	0.9	0.1	0.4	0.09
GOP aft2006	5	-	0.1	0.1	0.2	0.2	0.01
	12	-	0.3	0.3	0.4	0.4	0.06

Tab. 2: *The results of the six-month 'parallel' run in 2006*

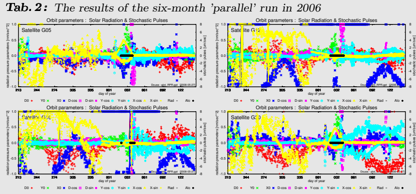

Fig. 9: *Changes of the deterministic orbit model in GOP solution (2007-2008)*

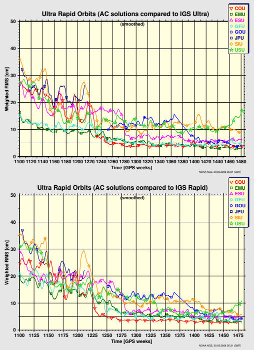

Fig. 8: *GOP orbits compared to IGU and IGR in 2006-2008 (Source: IGS ACC)*

- Dach R., Hugentobler U., Fridez P., Meindl M. (2007): Bernese GPS Software Version 5.0, Astronomical Institute, University of Bern.
- Beutler G., Brockmann E., Gurtner G., Hugentobler U., Mervart L., Rothacher M. (1994), Extended Orbit Modeling Techniques at the CODE Processing Center of the International GPS Service for Geodynamics (IGS): Theory and Initial Results, Manuscripta Geodaetica, 19, 367–386.
- Springer T.A., Beutler G., Rothacher M. (1999), Improving the Orbit Estimates of the GPS Satellites Journal of Geodesy, Vol 73, No 3, pp. 147–157.

IGS Analysis Center Workshop 2008 — MiamiBeach, Florida, USA, June 2 – 6, 2008.

Acknowledgement: This work was supported by Czech Science Foundation (205/09/0696) and the Ministry of Education, Youth and Sports of the Czech Republic (LC506).