

PRECISE ORBIT DETERMINATION OF GLONASS SATELLITES AT THE EUROPEAN SPACE AGENCY

I. Romero¹, C. Garcia¹, R. Kahle², J. Dow², and T. Martin-Mur³

¹*GMV at ESA/ESOC, Robert-Bosch-Str. 5, Darmstadt, D-64293, Germany*

²*European Space Operations Centre (ESOC), European Space Agency (ESA), Robert-Bosch-Str. 5, D-64293 Darmstadt, Germany*

³*Raytheon ITSS, 299 N. Euclid Ave., Suite 500, Pasadena, CA 91101, USA, (previously of ESA/ESOC)*

ABSTRACT

As an active Analysis Centre of the International GPS Service (IGS) the European Space Operations Centre (ESOC) joined the IGEX program for precise orbit determination of the GLONASS satellite constellation since its inception in 1998. This paper describes the orbit determination processing strategy, the specific GLONASS modelling issues implemented and a discussion of the processing results.

INTRODUCTION

ESOC has been processing GNSS data for precise orbit determination since 1991 with the analysis of the data from the GPS CIGNET-91 campaign. Therefore it was only logical that, when GLONASS data started being available in 1998, ESOC started developing the capabilities to process it to determine precise satellite orbits for the entire GLONASS constellation. This effort began as part of the International GLONASS Experiment (IGEX) which started within the IGS in 1998 (Willis et al, 1999). ESOC's submissions started in March 1999 with the analysis of GLONASS data from October 1998. Currently activities within IGEX continue with about 30 stations providing regular observation files and with three Analysis Centres processing this data to produce precise ephemerides and satellite clock biases for the constellation.

The structure of this paper is as follows: After this introduction the processing method for obtaining precise orbits of the GLONASS satellites is explained. The processing strategy is then presented, followed by some results and finally conclusions.

PROCESSING METHOD

The aim of the GLONASS data processing is to produce the highest possible quality satellite orbits for use by the scientific community. These orbit ephemerides are comprised of satellite positions every 15 minutes in an Earth reference coordinate system plus each of the satellites' clock bias. To produce these orbits the observables from high quality, dual-frequency GLONASS+GPS receivers are processed using the GPS-TDAF (Global Positioning System – Tracking and Data Analysis Facility). The GPS-TDAF is a set of software tools developed entirely at ESOC consisting of a data retrieval and storage system, a data pre-processor, a batch least-squares estimator for dynamic orbit determination and station parameter estimation, and a post-processor for formatting and presentation of satellite and station parameters. This section presents a general description of the GPS-TDAF and some specific details and enhancements introduced for GLONASS POD activities.

additional complexity of estimating both the satellite and station clock biases, which can be rapidly changing time-varying parameters.

The least squares estimator uses the dynamical and measurement models and the reference frames and time scales as specified in Dow and Martin-Mur (1999). The models implemented follow the work, among others, of Saastamoinen (1973) for the troposphere, Argus and Gordon (1991) for plate motions and Wahr (1979) for solid earth tidal displacements.

There was no previous knowledge of a GLONASS satellite solar radiation pressure model, therefore an empirical model has been developed and tested at ESOC. The final implementation of the empirical model assumes the following form for the force component on each of the three axes:

$$F_x = K(a_{x0}) \tag{1}$$

$$F_y = K(a_{y0}) \tag{2}$$

$$F_z = K(a_{z0} + a_{zc} \cos(A) + a_{zs} \sin(A)) \tag{3}$$

where K is a global scaling factor, the a_{ij} variables are the five estimated coefficients, and A is the solar anomaly, the angle in the orbital plane of the projected Earth-Sun vector and the Spacecraft-Earth vector as shown in Figure 2. The x direction in the equations above corresponds to the anti-sun, the y direction approximately along the solar panels and the z direction completes the right-handed coordinate system (Figure 2). The selection of this model was based on studying the residuals of the orbit determination and on the observability of the selected parameters.

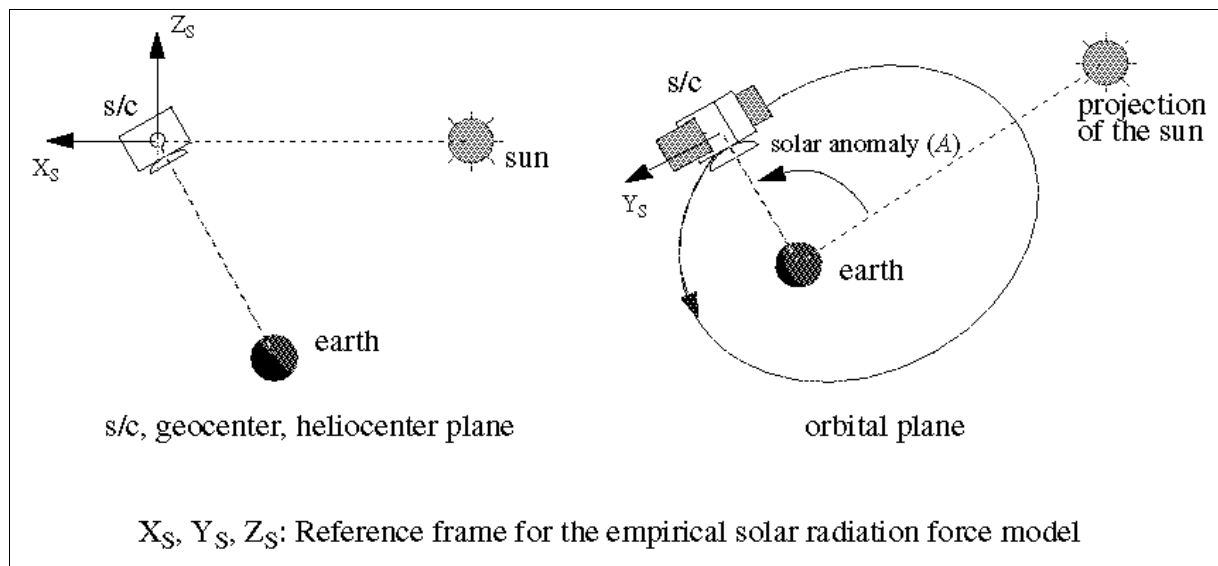


Fig. 2. The empirical solar radiation pressure model.

Finally the estimated parameters in the least-squares estimator are: The station coordinates, the satellite state vectors, and the solar radiation pressure model parameters, the undifferenced carrier phase ambiguities for the ionospheric linear combination, the GPS-GLONASS receiver biases, the Earth rotation parameters: x and y pole position and rates and Length of Day, the tropospheric zenith delay for every station every 2 hours, and station and satellite clock biases, estimated as time-dependent parameters (one value for every observation epoch).

Post-Processing

After the parameter estimation process, the results are formatted into standard ASCII file formats for distribution. This applies to the Earth Rotation Parameters, to the daily satellite ephemerides and clock biases and to the station coordinates, which are combined into a weekly SINEX file.

PROCESSING STRATEGY

Using the GPS-TDAF as described in the previous section the GLONASS precise orbit determination is conducted as follows:

1. RINEX observation and navigation files are retrieved from IGEX and IGS stations and stored locally in our computer system. The role of the IGS stations is to constrain the solution to the ITRF-97 so that GLONASS orbits and station coordinates solutions are represented in ITRF-97. Seven IGS stations are selected for this purpose. The IGEX and IGS stations normally used are:

IGEX stations: BIPD (France), BORG (Poland), CSIR (South Africa), DLFT and VSLD (Holland), CRAR, DAVR, and STR2 (Antarctica), GOPE (Czech Rep.), GODZ and USNX (USA), NPLC (England), GRAB and MTBG (Austria), KR0G and OS0G (Sweden), MTKA (Japan), REUN (La Reunion), REYZ (Iceland), SUNM and YARR (Australia), WTZZ (Germany), ZIMJ and ZIMZ (Switzerland).

IGS stations: ALGO (Canada), GOL2 (USA), KOKB (Hawaii), TID2 (Australia), ONSA (Sweden), VILL (Spain), TSKB (Japan).

2. For every day processed three days of data are used. This constitutes our data arc: the day we are processing, the day previous and the day after. The observation file containing the three days of data is then filtered to select the passes with at least 4 observations and with a controlled amount of noise between phase and pseudorange for every accepted pass.
3. The orbit determination using the least squares dynamic estimator is then started. The IGS GPS orbits from the ESA final solution and the station positions for the seven IGS stations are fixed, all other parameters for the stations and the parameters for the GLONASS satellites are estimated. The list of GLONASS satellites in the constellation and their status during the IGEX campaign is given in Table 1.

Table 1. GLONASS Constellation Status

	Slot no.	Designation	Intro. Date	Status
Plane 1	1	gv-82	18.02.1999	Processing OK
	3	gv-68	15.12.1994	Ended Transmission
	4	gv-70	11.12.1994	Ended Transmission
	6	gv-69	16.12.1994	Ended Transmission
	7	gv-80	29.01.1999	Processing OK
	8	gv-81	29.01.1999	Processing OK
Plane 2	9	gv-77	07.01.1996	Processing OK
	10	gv-75	22.08.1995	Bad Carrier Phase
	11	gv-76	22.08.1995	Processing OK
	13	gv-79	18.01.1996	Processing OK
	15	gv-78	26.04.1999	Processing OK
	16	gv-66	07.09.1994	Processing OK
Plane 3	17	gv-62	18.05.1995	Ended Transmission
	20	gv-71	30.03.1995	Ended Transmission
	22	gv-72	05.04.1995	Temp. Unavailable

4. Finally orbits and clocks are combined to produce an sp3 file for every day of processing, and station positions are combined into a SINEX file after a complete week is processed. The results are distributed weekly trying to keep the delay with real time to around three weeks.

RESULTS

Orbit Comparisons

To ensure that the orbit and clocks solutions for every day processed is of high quality an orbit and clock comparison is done for every day of processing between that day's solution and the solution for the same period during the previous day's processing. Since for every day of processing we process a three-day arc of data we always have an overlap period for comparisons. Figures 3 and 4 present RMS orbit differences for each day's orbit solution with the overlapping period of the previous day's solution for satellites gv-80 and gv-82, launched in Dec. 1998. Both figures show the RMS of the differences in the calculated orbits to be around or below 20 cm from day to day.

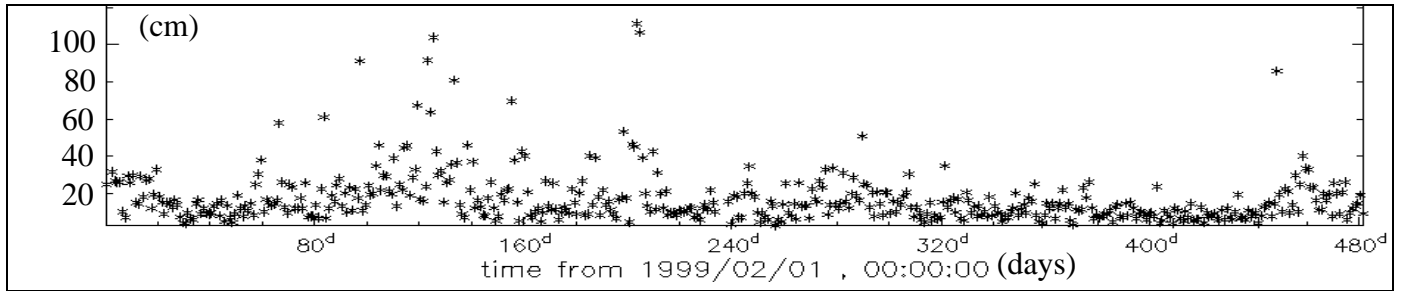


Fig. 3. gv-80 RMS orbit differences for overlapping processed data arcs.

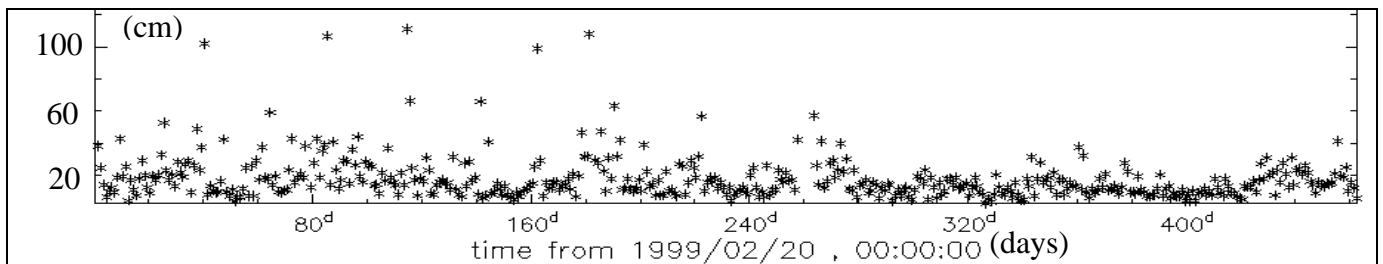


Fig. 4. gv-82 RMS orbit differences for overlapping processed data arcs.

For older satellites in the constellation the RMS of the differences for overlapping data arcs show considerable more scatter and larger differences from day to day. Figures 5 and 6 show results for satellites gv-77 and gv-66, launched in 1995 and 1994, respectively.

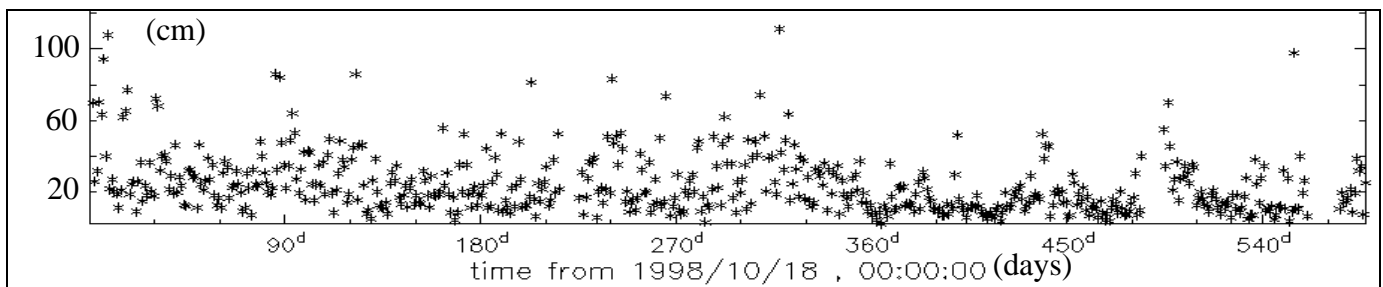


Fig. 5. gv-77 RMS orbit differences for overlapping processed data arcs.

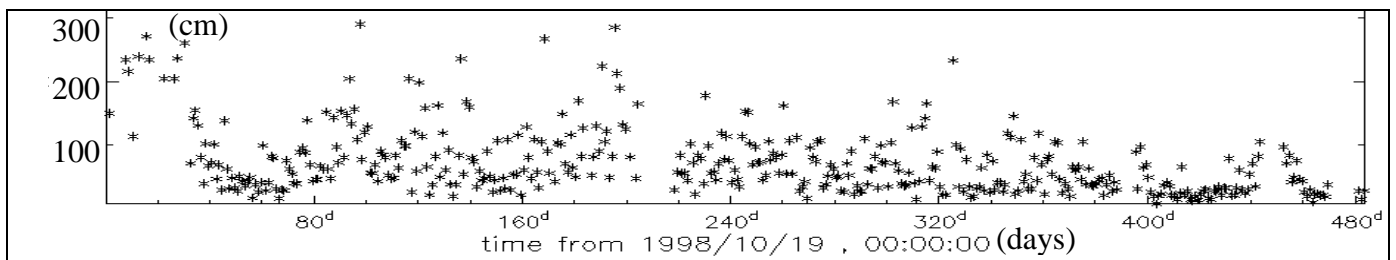


Fig. 6. gv-66 RMS orbit differences for overlapping processed data arcs.

A consistent trend that can be observed in the four figures above is that for the most part, as time has gone on, the differences with respect to the overlapping arc of the previous day of processing have become smaller, even for older satellites. This is due to two reasons, on the one hand our processing strategy has changed and improved in this time and also the size of the constellation has reduced considerably from around 14 satellites in the fall of 1998 to only about eight in the summer of 2000. With less satellites to estimate the solution tends to be more repeatable from day to day since there are less chances of unpredictable behaviour in one of the satellites which can affect the solution of the entire constellation.

Satellite Clock Bias Comparisons

The solution of the satellite clock biases is always included in the processed result files for each day of processing. They advise the user at every epoch of the differences between the satellite clock and a constant time scale. Results of comparisons between the calculated satellite clock biases from one day to the next over the overlapping data arc are shown in Figures 7 and 8 for satellites gv-82 and gv-77.

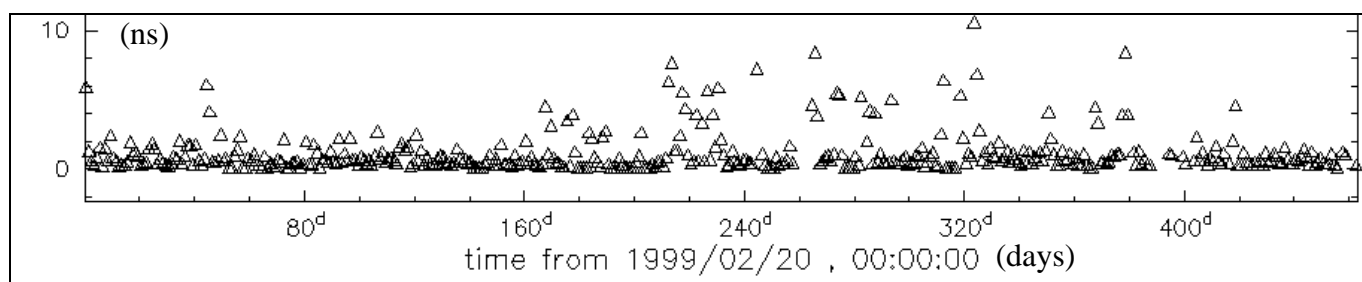


Fig. 7. gv-82 RMS Clock bias differences for overlapping processed data arcs.

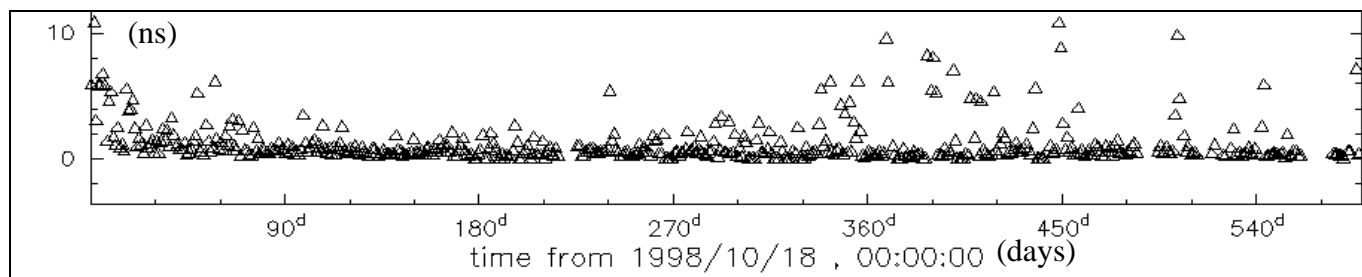


Fig. 8. gv-77 RMS Clock bias differences for overlapping processed data arcs.

The clock bias differences can be seen to be for the most part around or below 1 ns, showing that the repeatability for the satellites' clock biases is good.

GPS-GLONASS Bias

To be able to process GPS and GLONASS data at the same time a bias has to be estimated for each receiver at every station which models the different signal path or processing delay within the antenna, cable, amplifier or receiver for the GLONASS and GPS signals. The GPS-GLONASS biases are in most cases stable and depend mainly on the type of receiver being operated at each station. For example, the ASHTECH Z-18's receivers have offsets between -55 to 40 ns and day to day variations in the range of 1 to 3 ns, the Javad Legacy receivers show values between -150 to -220 ns, with similar day to day variations. This bias and the variations between receivers is given in Figure 9.

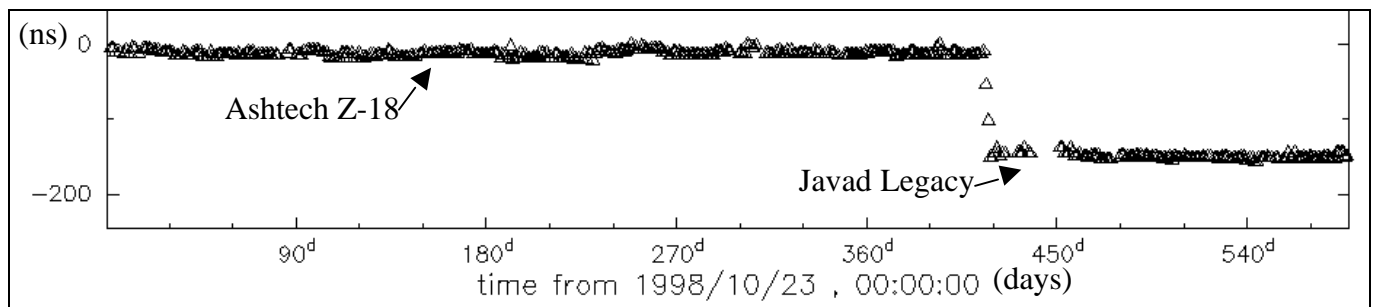


Fig. 9. GPS-GLONASS receiver bias for station OS0G at Onsala, Sweden.

Figure 9 shows the GPS-GLONASS bias for station OS0G (Onsala, Sweden) from October 1998 to June, 2000. The plot shows relatively stable biases for long periods of time with one large discontinuity, which corresponds to a receiver change at the station from an ASHTECH Z-18 to a Javad Legacy on the 14th December, 1999.

Empirical Solar Radiation Pressure Force Model

As discussed above, ESA/ESOC had no previous knowledge of a GLONASS satellite solar radiation pressure model. Therefore an empirical one was created as described by Eqs. 1, 2 and 3 and detailed in Figure 2 above. The results show that the components along each of the axes, as defined in Figure 2, are as follows: the x constant term is around 150 nN for all the satellites, the y constant term ranges between $\pm 0.5 \text{ nN}$ with cyclical variations throughout the year, the z constant term and the cosine term are scattered for the entire constellation between $\pm 1 \text{ nN}$ and the z sine term is about -3 nN .

CONCLUSIONS

The processing of GLONASS data at ESOC for POD has been a positive experience, the modifications necessary to our software and processing strategy have enhanced our capabilities. The processing is similar to that of GPS with the main differences of having to estimate a GPS-GLONASS bias for the receivers in order to simultaneously process GPS and GLONASS data and the implementation of an empirical solar radiation pressure model. ESOC will continue to process GLONASS data for POD, as long as a meaningful number of receivers and satellites are available, as part of the newly formed International GLONASS Service Pilot Project (IGLOS PP).

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