Combination of Multi-Satellite Techniques at the Observation Level

S. Zhu, Ch. Reigber, F.-H. Massmann, H. Neumayer, H. Meixner, F. Flechtner

GeoForschungsZentrum Potsdam, Germany
Section 1.2 "Development and Operation of Satellite Mission"

1 Introduction

Satellite techniques are very important for the IERS products EOP (incl. nutation) and terrestrial reference frame (station coordinates and their velocities). Currently the results from various satellite techniques are combined together at the normal equation level. The only link between them are the local ties of the collocation sites. For some years now, however, quite a number of satellites have been launched, which are equipped with instruments of more than one technique. In this paper we call it 'collocation (of multi-techniques) on board satellites'. Examples are: GPS35 and GPS36 (GPS sender + SLR); ENVISAT (SLR + DORIS); Jason and T/P (GPS receiver + SLR + DORIS); CHAMP and GRACE (GPS receiver + SLR). In order to fully exploit on-board collocation, combination at the observation level is necessary.

The laser reflector on board the GPS 35 and 36 satellites have proved to be useful for detecting systematic errors between the two systems. Combining the two data types at the observation level helps to improve the solution slightly, as shown in (Zhu et al. 1997). But the amount of SLR data available is far from enough to do this on a routine basis.

T/P is a different example. A few institutes have used both SLR and DORIS tracking data for the orbit restitution. In this case, these two techniques have already been combined at the observation level. As the adjustment is done with SLR and DORIS data simultaneously, the correlation block between SLR and DORIS stations of the comprehensive covariance matrix is non-zero after the reduction of the dynamical orbit parameters. This provides a strong link between the two systems, and it plays a role as a complement to the ground collocation.

GPS receiver on board LEO satellites is a very important development. For the routine orbit determination of CHAMP and GRACE, a so called 'two-step' method is adopted. First, GPS data from ground stations are used to determine the orbits of the GPS satellites, then they are fixed in order to restitute the LEO orbit by the on-board GPS data. The 'one-step' method, by contrast, is to combine the ground and on-board data together at the observation level and determine simultaneously the orbits of the LEO and GPS satellites, together with the EOP and station positions. The geocenter and scale are weak points of the GPS (ground) solutions, see Zhu et al. (2002). As a LEO satellite is much lower than GPS satellites, it is much more sensitive to the gravity field, including the first degree terms (i.e. geocenter). Tropospheric zenith delays (TZD) need not to be solved. For ground stations, TZP are highly correlated with the height. This is one of the major reasons why the scale of the GPS terrestrial system is not stable. These weaknesses of the GPS technique could be improved by LEO missions. LEOs form a middle altitude layer. Together with ground layer and GPS high altitude layer, this three layers construction makes the GPS solutions more robust and consistent, see Rothacher (2003). This structure also improves the LEO orbits (accordingly the gravity solutions), as can be seen in the tests of the next section.

A more comprehensive case is to combine LEO and ground GPS data together with other observation types, such as SLR and DORIS. In order to do this combination effectively, some difficulties needed to be overcome, e.g. the arc length problem. GPS ground data processing adopts 1–2 day arc length due to the CPU time and the large amount of unknowns. But such short arc lengths are not sufficient to determine SLR and/or DORIS site positions with adequate accuracy.

Above are only a few examples of the on board collocation pattern. With the increasing number of LEOs, the method of combination at the observation level will become more and more important.

2 Test results

In this section a few test results are given in order to show the improvements brought by the method of combination at the observation level. We take the GRACE twin-satellites as an example. The software EPOSOC of GFZ is used.

The results of two 1.5-day arcs are given in Table 1. The values given in the second row are from the two step method. GPS data from more than 40 ground sites are used to compute the GPS orbits and clock corrections; then GRACE GPS data are used to compute the GRACE orbits. In this run SLR, K-band range and range rate data are used only for quality control, and do not play a role in the adjustment. The corresponding results of the one step solutions are shown in the third row. From these numbers one sees clearly the benefit brought by the one step method. Actually, in the two step method, the orbits of grace A and B are independently solved, there is no correlation between the two normal equations. But in the latter case, the orbits are correlated, similar as the coordinates of two neighbouring ground stations. This correlation reduces the uncertainty of the orbit differences between GRACE A and B, and thus improves significantly the residuals of K-band data. The quality of the absolute orbit positions, as judged by the SLR residuals, is also improved, but not so drastically. For the gravity solution the improvement of the relative position between two satellites is of substantial importance.

The one step method is not only profitable for GRACE orbits, but the GPS orbits and GPS reference frame are improved, too. For instance, comparing the GPS orbits of the two step method with IGS orbits, the rms difference was about 6 cm, while that of the one step was 5 cm. If data from more LEO are used, the improvement could be more significant.

In the last row of Table 1 the orbits were restituted by using also the GRACE SLR data. This is a complete combination at the observation level. About one hundred SLR data per day are available, less than 1% of the GPS data amount (of the GRACE). Therefore the improvement is small. But the trend is as we expected.

Table 1 Comparison of various processing methods (rms residuals).
arc 1 (020503.0h–020504.12h) / arc 2 (020504.12h–020506.0h)

	K-band Range cm	Range Rate mm/s	SLR cm
2 step	1.55 / 1.88	.0129 / .0188	4.89 / 4.21
1 step	.823 / 1.327	.00632 / .00954	4.05 / 4.09
1 step + SLR	.799 / 1.325	.00599 / .00950	3.70 / 1.47

References

Rothacher, M., this volume, 2003

Zhu, S.Y., Reigber, Ch., Kang, Z., Apropos laser tracking to GPS satellites. Journal of Geodesy, vol. 71, pp. 423–431, 1997

Zhu, S.Y., Massmann, F.-H., Yu, Y., Reigber, Ch., Gravity Model induced Systematic Errors in Reference Frames. Proceedings of the IAG Scientific Assembly (Vistas for Geodesy in the New Millennium), 2–7 Sept. 2001, Budapest, Hungary, pp. 15–17, 2002