GPS orbit improvement based on combined POD with LEO satellites

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Abstract

The Precise Orbit Determination (POD) of GPS and Low Earth Orbit (LEO) satellites are usually performed independently. In recent years, few studies have combined the processing of ground and space-based GNSS observations. The combined POD of GPS and LEO satellites, i.e. GRACE-A/B, Jason-2/3, Swarm-A/B/C, is discussed in this study. GPS code and phase observations obtained by GPS receivers onboard the LEO satellites and ground-based receivers of 26 stations of the IGS tracking network are processed together in one least-squares adjustment. The POD solution of the combined processing with different subsets of the above-mentioned LEO satellites are analyzed in detail. The derived GPS orbits are validated by comparing with IGS products, orbit overlap analysis and statistical analysis.

The GPS-only POD based on the observations from above-mentioned 26 IGS stations is a baseline result. Comparing with this baseline result, the GPS orbit accuracy improves from 13.67% up to 33.67% with different numbers of LEO satellite combined.

Combined POD

In the combination, the dynamic modelling of GPS and LEO satellites is independent, while the ground and on-board GPS observations are processed simultaneously in a least-squares adjustment to estimate the initial state and force model parameters of all satellites. Figure 1 presents the flowchart of combined POD applied in PANDA software (Liu and Ge 2003). The methodology of the simultaneous least-squares estimation is also known as 'One-step' approach (Geng et al. 2008).

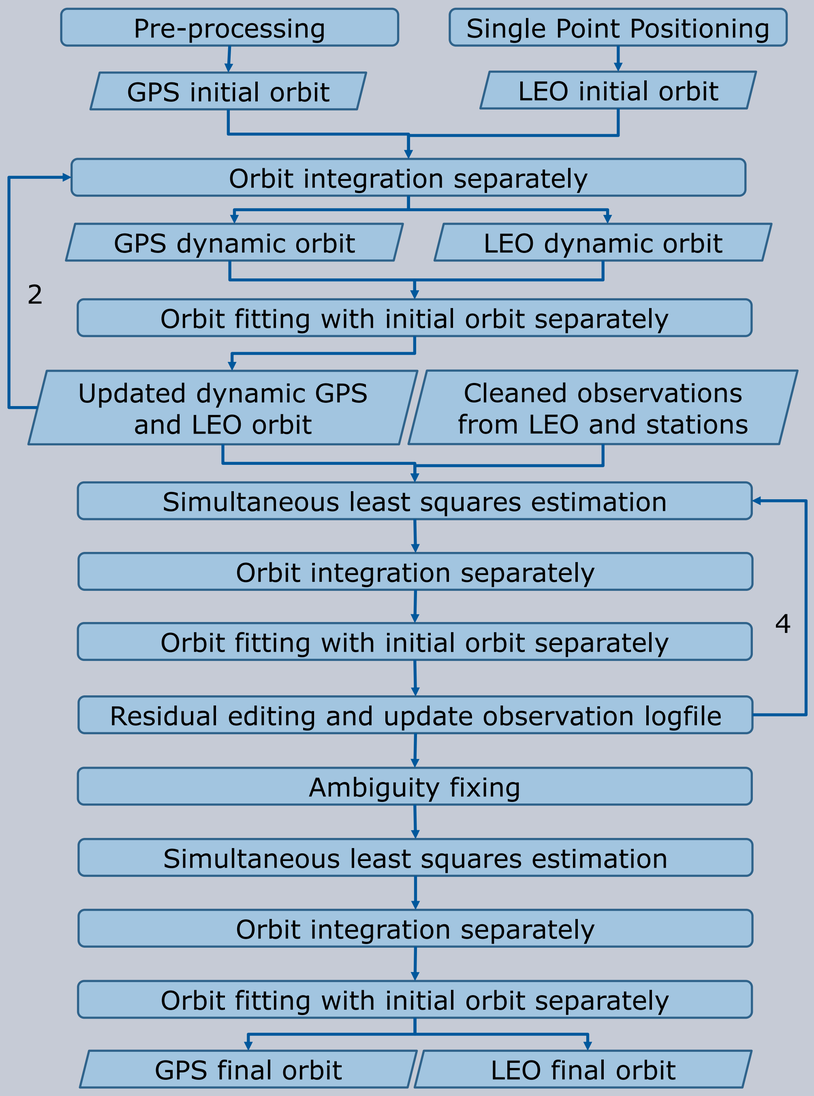

Fig. 1 *Flowchart of combined POD applied in PANDA software (number 2 and 4 mean iteration times).*

Acknowledgement

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The main processing is base on PANDA software.

The data of GRACE-A/B, Jason-2/3 and SWARM-A/B/C are provide by ISDC, AVISO and ESA.

GPS ground observations and related products are provided by IGS.

References

Geng J, Shi C, Zhao Q, Ge M, Liu J (2008) Integrated adjustment of LEO and GPS in precision orbit determination. International Association of Geodesy Symposia 132:133–137, DOI 10.1007/978-3-540-74584-6-20

Liu J, Ge M (2003) PANDA software and its preliminary result of positioning and orbit determination. Wuhan University Journal of Natural Sciences 8(2):603–609, DOI 10.1007/BF02899825

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Data availability and processing period

After checking the data availability of 26 ground stations and 7 LEO satellites, the days of year (DOY) 115 to 260 in 2016 are selected as investigation period. GPS satellites with maneuvers and days with missing or low quality LEO data were excluded. Finally, 112 days denoted as green dots in Figure 1 are processed for this study.

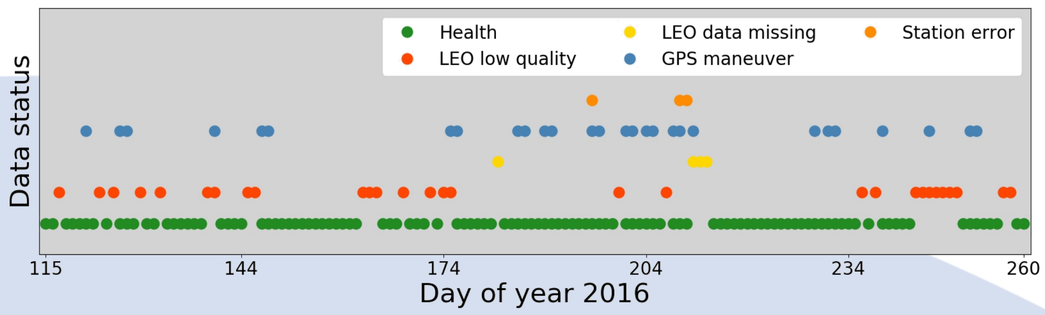

Fig. 2 *Status of on-board and ground station GPS observation data in the selected time period.*

Ground station networks and LEO satellite constellations

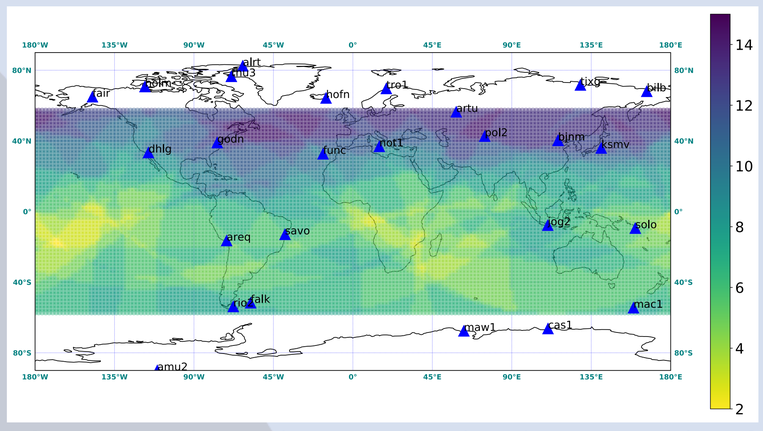

Fig. 3 *Selected ground station network and station visibility of each GPS satellite position.*

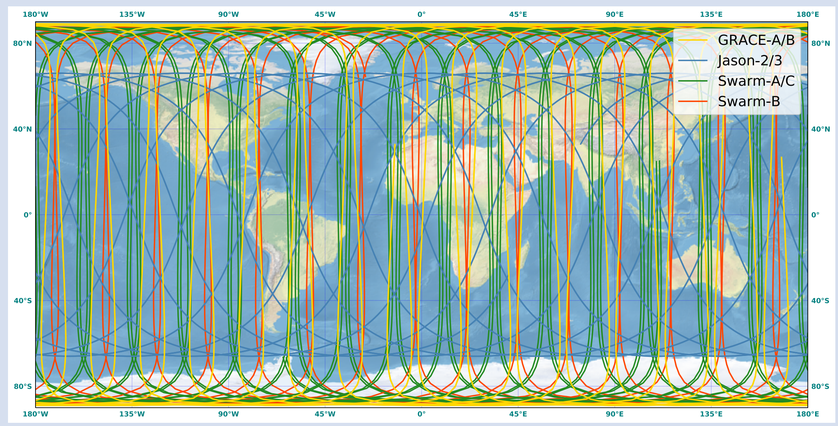

Fig. 4 *Ground track of seven LEO satellites.*

The rigorously selected 26 IGS stations are presented in Figure 2. The stations are homogeneously distributed, except for some special regions, i.e. the Pacific Ocean and Africa, to access the impact of gaps in the ground stations coverage on derived orbit. The color of each grid presents how many stations can be seen from a fictitious GPS satellite position. The lack of observations are obvious in the regions mentioned above.

The seven LEO satellites are in 4 different orbital planes which are shown in Figure 3 with altitude between 400 and 1360 km.

Improvements of GPS orbit

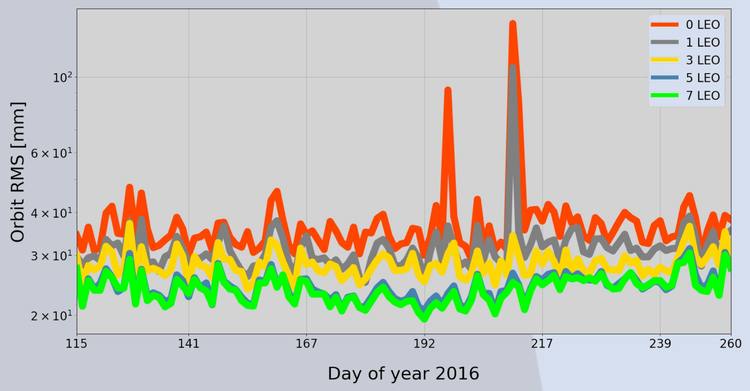

Fig. 5 *GPS orbit accuracy of combined POD with different numbers of LEOs compared against IGS final orbit (log. scale).*

LEO number	LEO name	RMS [*mm*]	Improvement [%]
0	-	37.5	-
1	Jason-2	31.8	13.67
3	add Swarm-A and Swarm-C	27.2	24.97
5	add Jason-3 and GRACE-B	24.9	31.19
7	add Swarm-B and GRACE-A	23.9	33.67

Table. 1 *Average accuracy and improvement of GPS orbit of the processed days.*

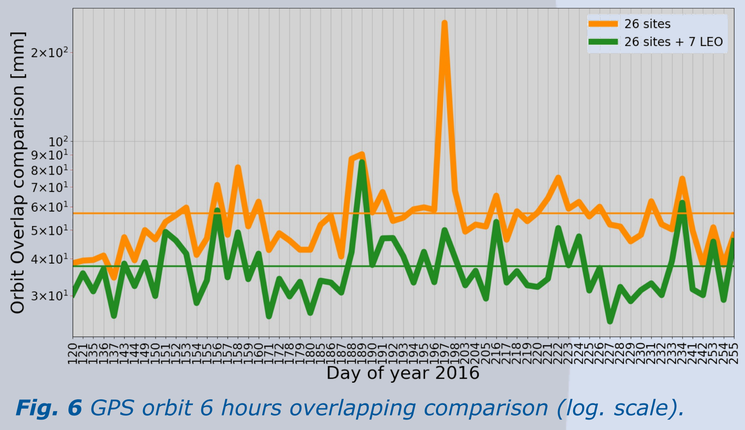

Fig. 6 *GPS orbit 6 hours overlapping comparison (log. scale).*

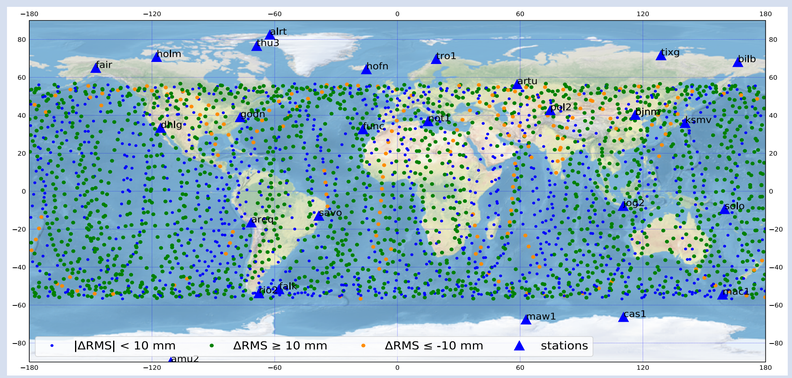

Fig. 7 *GPS ground track, color-coded orbit improvement w.r.t. IGS final orbit (combined POD with 3 LEO satellites in DOY 183).*

- Table 1 and Figure 5 present the GPS orbit accuracy in different schemes and improvement by combined POD against 26-ground-stations-only solution in time series and average.
- Figure 7 is an example (combined POD with 3 LEO satellites on DOY 183) plot of GPS orbit improvements corresponding to the ground track. The green dot means that GPS orbit improves more than one centimeter. And the orange one means opposite. The blue ones denote that the changing of orbit accuracy is within one centimeter.
- 6-hour overlapping comparisons of GPS orbits are processed. The results are shown in Figure 6. The orange curve is the solution of 26-ground-station-only GPS POD. And the green one is the solution of the combined POD with seven LEO satellites.
- The peaks in Figure 5 (DOY 196, 209, 210) and Figure 6 (DOY 196) are caused by observation errors from some ground stations. These days are also denoted as orange dots in Figure 2.

Conclusions and further study

GPS orbit can be improved by adding LEO satellites to a combined POD. The improvement increases with adding more LEO satellites. Especially, when there are big errors related to ground station observations, the improvement of GPS orbit is significant. In regions without ground stations, the improvement is obvious.

The impact of adding different LEO satellites on the GPS orbit improvements can be discussed. The factors affecting the improvements, for example LEO orbital plane inclination, are under study. The improvements of combined POD with 5 or 7 LEO satellites are very similar. The limit of the improvement is under investigation.