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# Precise Galileo orbit determination using combined GNSS and SLR observations

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The European navigation system Galileo is on its final stretch to become a fully operational capability (FOC) Global Navigation Satellite System (GNSS). The current constellation consists of 24 healthy satellites decomposed into three Medium Earth Orbits and since late 2016 is considered as an operational system. So far, the official Galileo orbits are provided by the European Space Agency and in the frame of the International GNSS Service (IGS) Multi-GNSS pilot project (MGEX) whose one of the goals is to develop orbit determination strategies for all new emerging navigation satellite systems.

All the Galileo satellites are equipped with Laser Retroreflector Arrays (LRA) for Satellite Laser Ranging (SLR). As a result, a number of Galileo satellites is tracked by laser stations of the International Laser Ranging Service (ILRS). SLR measurements to GNSS, such as Galileo, comprise a valuable tool for the validation of the orbit products as well as for an independent orbit solution based solely on laser ranging data. However, the SLR data may be used together along with the GNSS observations for the determination of the combined GNSS orbit using the two independent space techniques co-located onboard the Galileo satellites. The Galileo orbit determination strategies, as well as the usage of laser ranging to the navigation satellites, is crucial, especially in the light of the discussion concerning possible usability of the Galileo observation in the future realizations of the International Terrestrial Reference Frames.

In this study, we present results from the precise Galileo orbit determination using the combined GNSS data transmitted by the Galileo satellites and the range measurements performed by the ILRS stations. We test different weighting strategies for GNSS and SLR observations. We test the formal errors of the Keplerian elements which significantly decrease when we apply the same weights for SLR and GNSS data. However, in such a manner, we deteriorate the internal consistency of the solution, i.e., the orbit misclosures.

For the solution with optimal weighting strategy, we present results of the quality of Galileo orbit predictions based on the combined solutions, as well as the SLR residuals. The combined GNSS+SLR solution seems to be especially favorable for the Galileo In-Orbit Validation (IOV) satellites, for which the standard deviation (STD) of the SLR residuals decreases by 13% as compared to the microwave solutions, whereas for the Galileo-FOC satellite the improvement of the STD of SLR residuals is at the level of 9%. Finally, we test the impact of adding SLR observations

to the LAGEOS satellites which stabilizes the GNSS solutions, especially in terms of the realization of terrestrial reference frame origin.