General Relativistic effects acting on GNSS orbits with a focus on Galileo satellites launched into incorrect orbital planes

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Three orbital effects emerging from general relativity are typically considered for Earth-orbiting satellites: the Schwarzschild effect, Lense-Thirring effect or frame-dragging, and the de Sitter or geodetic precession effect. For circular orbits and short satellite orbital arcs, the dominating Schwarzschild effect is difficult to determine, because it causes a constant radial acceleration which can be absorbed by a small modification in the gravitational constant GM term or a constant offset in the estimated semi-major axis of a satellite orbit. To separate the effects caused by the Schwarzschild effect from other orbital effects, especially those emerging from orbit modeling issues of non-gravitational accelerations, eccentric satellite orbits should be employed.

The first pair of satellites belonging to the Galileo satellite system was accidentally launched into non-circular orbits with height variations between from 17,180 km for the perigee to 26,020 km for the apogee. The eccentric orbits introduced new opportunities for the verification of the effects emerging from general relativity when employing the Galileo constellation. Galileo satellites are equipped with two techniques for precise orbit determination: microwave GNSS antennas and SLR retroreflectors which allow for deriving their orbits of superior quality.

In this study, we discuss effects in GNSS orbits emerging from general relativity. We concentrate on those effects that exceed the value of 1 mm over 1 day, thus are of fundamental importance for precise orbit determination in satellite geodesy and precise high-quality products of the International GNSS Service. We show that the semi-major axis of Galileo satellites in eccentric orbits varies between -29 mm in perigee to -9 mm in apogee due to the Schwarzschild term. For GNSS geostationary satellites with the inclination angle close to zero, the omission of the de Sitter effect may cause an error of the determination of the right ascension of ascending node exceeding the value of 1 meter after 1 day. Finally, we discuss the suitability of using GPS, GLONASS, and Galileo satellite orbits to determine the values of the Post-Newtonian Parameters γ and β and all limitations related to the observability of these parameters at GNSS heights and systematic errors emerging from non-gravitation orbit perturbations.