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# Geometrical Model of Solar Radiation Pressure Based on High-Performing Galileo Clocks - First Geometrical Mapping of the Yarkowsky effect

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Solar radiation pressure is the main source of errors in the precise orbit determination of GNSS satellites. All deficiencies in the modeling of Solar radiation pressure map into estimated terrestrial reference frame parameters as well as into derived gravity field coefficients and altimetry results when LEO orbits are determined using GPS. Here we introduce a new approach to geometrically map radial orbit perturbations of GNSS satellites using highly-performing clocks on board the first Galileo satellites. Only a linear model (time bias and time drift) needs to be removed from the estimated clock parameters and the remaining clock residuals map all radial orbit perturbations along the orbit. With the independent SLR measurements, we show that a Galileo clock is stable enough to map radial orbit perturbations continuously along the orbit with a negative sign in comparison to SLR residuals. Agreement between the SLR residuals and the clock residuals is at the 1 cm RMS for an orbit arc of 24 h. Looking at the clock parameters determined along one orbit revolution over a period of one year, we show that the so-called SLR bias in Galileo and GPS orbits can be explained by the translation of the determined orbit in the orbital plane towards the Sun. This orbit translation is due to thermal re-radiation and not accounting for the Sun elevation in the parameterization of the estimated Solar radiation pressure parameters. SLR ranging to GNSS satellites takes place typically at night, e.g. between 6 pm and 6 am local time when the Sun is in opposition to the satellite. Therefore, SLR observes only one part of the GNSS orbit with a negative radial orbit error that is mapped as an artificial bias in SLR observables. The Galileo clocks clearly show orbit translation for all Sun elevations: the radial orbit error is positive when the Sun is in conjuction (orbit noon) and negative when the Sun is in opposition (orbit midnight). The magnitude of this artificial negative SLR bias depends on the orbit quality and should rather be called GNSS orbit bias instead of SLR bias. When LEO satellite orbits are estimated using GPS, this GPS orbit bias is mapped into the antenna phase center. All LEO satellites, such as CHAMP, GRACE and JASON-1/2, need an adjustment of the radial antenna phase center offset. GNSS orbit translations towards the Sun in the orbital plane do not only propagate into the estimated LEO orbits, but also into derived gravity field and altimetry products. Geometrical mapping of orbit perturbations using an on board GNSS clock is a new technique to monitor orbit perturbations along the orbit and was successfully applied in the modeling of Solar radiation pressure. We show that CODE Solar radiation pressure parameterization lacks dependency with the Sun's elevation, i.e. elongation angle (rotation of Solar arrays), especially at low Sun elevations (eclipses). Parameterisation with the Sun elongation angle is used in the so-called T30 model (ROCK-model) that includes thermal re-radiation. A preliminary version of Solar radiation pressure for the first five Galileo and the GPS-36 satellite is based on 2×180 days of the MGEX Campaign. We show that Galileo clocks map the Yarkowsky effect along the orbit, i.e. the lag between the Sun's illumination and thermal re-radiation. We present the first geometrical mapping of anisotropic thermal emission of absorbed sunlight of an illuminated satellite. In this way, the effects of Solar radiation pressure can be modelled with only two paramaters for all Sun elevations.