Doppler orbit determination of deep space probes by the Bernese GNSS Software: first results of the combined orbit determination from DSN and inter-satellite Ka-Band data from the GRAIL mission

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Navigation of deep space probes is most commonly operated using the spacecraft Doppler tracking technique. Orbital parameters are determined from a series of repeated measurements of the frequency shift of a microwave carrier over a given integration time. Currently, both ESA and NASA operate DSN antennas on several sites around the world to ensure the tracking of deep space probes using S-band , X-band and Ka-band one-way, two-way and three-way radio links. Doppler measurements are also commonly used in planetary geodesy, where the spacecraft orbit is used as basis for the determination of the gravity field coefficients.

Just a small number of software packages are nowadays used to process Doppler observations, e.g. GEODYN (NASA GSFC), MIRAGE/MONTE (NASA JPL), GINS (CNES) and ESOC's Orbit Determination System (ESA). The Astronomical Institute of the University of Bern (AIUB) has recently started the development of Doppler data processing capabilities within the Bernese GNSS Software . This software has been extensively used for Precise Orbit Determination (POD) of Earth orbiting satellites using GPS data collected by on-board receivers and for subsequent determination of the Earth's gravity field. Based on the GRACE processing chain established at AIUB, procedures have been extended to also perform orbit and gravity field determination from data collected by the NASA mission GRAIL (Gravity Recovery And Interior Laboratory). This mission uses both Doppler tracking from Earth and ultra-precise inter-satellite Ka-band range-rate (KBRR) observations, which has enabled for the first time data acquisition also on the entire far-side of the Moon. This data allows for highly accurate lunar gravity field determination, as demonstrated by the spectacular high resolution solutions computed at NASA GSFC and NASA JPL.

In this paper, we present the currently achieved status of the DSN Doppler data modeling and orbit determination capabilities in the Bernese GNSS Software using GRAIL data. In particular we will focus on the implemented orbit determination procedure used for the combined analysis of DSN and Ka-band data. Despite the heritage from GRACE, there are major differences, e.g., due to the inhomogeneous coverage of the GRAIL orbits by DSN tracking.

First, we will solve a classical orbit determination problem for each GRAIL satellite separately by using only Doppler data. Orbits will be parametrized by initial osculating orbital elements and a small number of empirical orbit parameters to handle remaining model deficiencies when using lunar gravity field models of modest quality. The orbits emerging from this procedure will then serve as a priori orbits for the subsequent Ka-band analysis. Thanks to the ultra-precise KBRR measurements, additional empirical orbit parameters can be set up to fit both the KBRR and the Doppler observations on their respective accuracy levels. To preserve numerical precision, orbital parameters will be set up as mean and (half) differences of the original orbital parameters. Using the outlined procedure the optimal weighting and empirical orbit parametrization will be assessed when using gravity field models of different qualities, e.g., the solutions emerging from the GRAIL mission and from the pre-GRAIL era. The internal quality of the resulting orbits over both the near- and far-side of the Moon will be assessed.