Geophysical Research Abstracts
Vol. 16, EGU2014-7934-2, 2014
EGU General Assembly 2014

Terrestrial and Celestial Reference Frame Realization with Highly Elliptical Orbit - The ESA STE-QUEST Mission

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The Space-Time Explorer and QUantum Equivalence Principle Space Test (STE-QUEST) is a Medium Class fundamental physics mission pre-selected for the M3 slot of the ESA Cosmic Vision Programme to test Einstein's Equivalence Principle using atom interferometry and the general and special theory of relativity. Two secondary mission objectives are related to space geodesy: terrestrial and celestial reference frame of the Earth and relativistic geodesy aiming at the realization of unified reference frame for positioning, time, and temporal gravity. The highly elliptical orbit of the STE-QUEST satellite can be used for terrestrial reference frame realization by means of on board GNSS, SLR and VLBI radio source (STE-QUEST metrology link tracked by VLBI antenna – compatible with VLBI2010). By upgrading the on board GNSS receiver for DORIS tracking, the STE-QUEST mission will be similar to the GRASP mission proposal from JPL. Due to the highly elliptical orbit of STE-QUEST (apogee <50 000 km) the satellite dwells in the apogee and can be observed for a long time against the quasars (e.g. 10 hours) defining the celestial reference frame. The proposed scientific objectives of the STE-QUEST mission related to space geodesy are as follows:

1) meet the GGOS (Global Geodetic Observing System) goals for a terrestrial reference frame of the Earth, i.e. 1 mm accuracy and 0.1 mm/yr stability
2) implement the realization and unification of the terrestrial and celestial reference frames of the Earth
3) improve the orbit accuracy of GNSS satellites (GPS, GLONASS, Galileo) by tracking orbits of GNSS constellations and SLR reference frame satellites against STE-QUEST highly elliptical orbit and quasars defining the celestial frame (double-difference SLR/GNSS/VLBI approach)
4) properly align the GAIA optical reference frame with the unified terrestrial and celestial reference frame and common optical/radio quasars observed at higher VLBI frequencies (that are closer to optical positions)
5) determine the long-wavelength variability in the gravity field of the Earth including central term and low degree spherical harmonic coefficients that are either not observed or poorly observed by GRACE and GOCE gravity field missions (e.g. dynamic flattening of the Earth)
6) significantly improve satellite altimetry (Jason-2, Sentinel-3) and tide gauge records of global mean sea level rise by using the highly accurate terrestrial reference frame from the STE-QUEST mission
7) contribute to the monitoring of mass transport in polar regions (ice mass loss) by referencing altimetry (Cryosat, ICESat) and gravity data (GOCE and GRACE gravity missions) to the common terrestrial reference frame from the STE-QUEST mission
8) contribute to the monitoring of the Earth's rotation and orientation parameters making use of the highly elliptical orbit of the STE-QUEST mission (UT1, LOD variations, etc.) and VLBI tracking from the ground
9) provide a common time scale for all space geodesy techniques (GNSS, DORIS, VLBI and SLR)
10) disseminate the terrestrial/celestial reference frame anywhere on Earth or in space (altimetry/gravity missions in LEO orbit, BepiColombo, etc.)

A highly elliptical orbit is a sensor, not only for Earth rotation and orientation, but also for the estimation of low degree spherical coefficients of the Earth's gravity field that are either not observed or poorly observed by the GRACE and GOCE gravity field missions. Geometrical VLBI mapping of the STE-QUEST orbit against extragalactic radio-sources can be realized by observing quasars at the approximate locations of the STE-QUEST satellite. This is similar to the Delta-DOR approach used in the tracking of interplanetary satellites. The STE-QUEST satellite dwells for a long time at the apogee of a highly elliptical orbit, providing a perfect target for a

ground network of VLBI radio-telescopes in order to map the satellite orbit and the associated terrestrial frame against the positions of extra-galactic radio sources. The same stands for GNSS satellites that can be observed relative to the STE-QUEST orbit using same-beam interferometry. In this way, we will be in a position, for the first time, to combine the geometrical celestial frame from VLBI and the dynamic terrestrial reference frame from GNSS constellations, SLR and DORIS satellites. In a similar way, using a double-difference SLR (first results presented here), VLBI and GNSS approach, the orbits of GNSS satellites and SLR reference frame satellites can be dynamically mapped against the highly elliptical orbit of the STE-QUEST mission. From this point of view and with the unique suite of STE-QUEST instruments, the highly elliptical orbit of STE-QUEST is the best orbit for the combination of all space geodesy techniques such as GNSS, VLBI, SLR and DORIS, and unification of the celestial and terrestrial reference frames of the Earth.

The orbit of the STE-QUEST mission is designed to allow for long common-view frequency comparison between clocks located at different continents. Such measurements can be used to establish a global reference frame for time and the gravitational potential of the Earth. This reference frame could be used for the realization of TAI (International Atomic Time), as well as to support realization of the global height system. First ground optical clocks reached frequency stability at the 10^{-18} level that corresponds to 1 cm in terms of geoid height. Temporal gravity field maps are provided on routine basis by the GRACE mission, however with significantly lower resolution compared to the static gravity field. Therefore, it will be very interesting to use the STE-QUEST mission to establish a unified terrestrial reference frame for positioning, time, and temporal gravity field of the Earth.