21st International Workshop on Laser Ranging
Session 3 Summary
"Satellite Missions and Techniques for Geodetic Applications"

Session Chairs: John Degnan (Sigma Space Corporation), Ulrich Schreiber (TUM), Andrey Sokolov (RPC "PSI", JSC)

1. The authors suggest using a large number of smaller, inexpensive COTS cubes in order to meet both the cross-section and 1 mm range accuracy requirement.
2. On May 22nd 2018 the two Gravity Recovery and Climate Experiment (GRACE) Follow-On satellites, were launched successfully into their 490 km circular polar orbit and will continue the monitoring of Earth's gravity field from space on a monthly basis. From the differences between monthly solutions, changes of mass in ice sheets and terrestrial storages can be inferred for all regions of the globe. Such data shall be used to answer questions related with climate change, such as the future trend of sea level rise and the increasing use of ground water.
3. SLR measurements have been used to improve the understanding for GNSS orbit modelling. The SLR measurements have significantly helped to establish a reasonable modelling of Solar radiation pressure for the satellites in the new constellations (Galileo, BeiDou). One example was the detection of a certain change of the behavior of GLONASS satellites after three to four years of their lifetime thanks to the long history of SLR tracking data to these satellites.
4. This presentation provides an overview the Ranging And Nanosatellite Guidance Experiment (RANGE) mission, its expected outcomes, as well as the specific hardware and mission design made to accommodate ground-based laser ranging. RANGE is a two-satellite cubesat mission with the goal of improving the absolute and relative positioning capabilities of small satellites. The twin satellites will fly in a leader-follower formation and will carry dual-frequency GNSS receivers, as well as an inter-satellite ranging system and a miniaturized atomic clock.
5. The Japanese Quasi-Zenith Satellite System (QZSS) is a regional satellite positioning system in Asia-Pacific region. A four satellite constellation(3-QZO, 1-GEO) was established in 2017, and the full operational service will be started in Nov.2018. The positioning signal is fully compatible with US-GPS. The QZSS at high elevation angles reduces the multipath effect especially in near JAPAN Area. Service users can improve Dilution Of Precision (DOP) by mutual use of US-GPS and QZSS.
6. The status of the European Laser Timing (ELT) hardware was presented. Both the ground and space segments of the laser time transfer instrumental chain were upgraded. As a result, the frequency transfer uncertainty of the order of 1 x 10E-18 after several days of integration time may be achieved. The application of this improved laser time transfer technology with respect to orbiting optical clocks (dubbed ELT+), is expected in a near future.

7. The European Laser Timing (ELT) is an optical time transfer experiment that will be carried out to the ESA mission ACES (Atomic Clock Ensemble in Space). This fundamental physics mission will bring two high performance clocks on board of the international space station (ISS). The clocks will be combined to compose a timescale of unprecedented accuracy and precision in space. The optical time transfer between ground clocks and the ACES timescale will be carried out by SLR stations equipped with hydrogen masers. The current paper describes a Monte Carlo Simulation carried out to verify the targeted precision for time program.
8. Optical two way time transfer between ground stations in common view can be achieved by diffuse reflections from space debris items. These echo signals are detected by both stations individually from time of flight measurements of short laser pulses. Modeling the tumbling motion of the selected space debris target allows for a significant reduction of the return signal scatter. Uncertainties for the transfer of time appear to be reducible to less than 100 ps. This paper outlines the application of the Lomb-Scargle algorithm and illustrates it's application to accurate optical time transfer over larger distances.
9. The LightSail 2 project will demonstrate controlled solar sailing in Earth orbit from a 3U CubeSat platform. Scheduled for launch in late 2018, LightSail 2 will be injected into a 720 km, 24 deg inclination orbit. Following an on-orbit checkout period, LightSail 2 will deploy a 32 square meter solar sail, and control the sail orientation relative to the Sun to raise orbit apogee. Laser ranging to determine the LightSail 2 orbit is planned both before and after sail deployment. With no global positioning system receiver on board the spacecraft, LightSail 2 is dependent upon two-line element data sets for coarse orbit determination. Laser ranging measurements will provide refined orbit determination prior to sail deployment. Following sail deployment, additional laser ranging observations are planned, although targeting will be challenging due to the rapidly changing orbit. Stations within 30 deg of the equator will be able to observe LightSail 2.
10. The S-NET mission consists of four nanosatellites (each 9 kg) flying in a close train configuration to perform intersatellite communication demonstration. Each satellite is equipped with a unique reflector pattern on its nadir side by varying the number of 10mm fused silica cubes. After successful orbit insertion of the satellites on Feb. 1st 2018, the first SLR return was obtained on April 12th. The continuous tracking supported the object identification and precise formation analysis. The presentation shows the mission flight results and lessons learned from the laser ranging of the S-NET mission.
11. The influence of different laser beam polarization states on satellite laser ranging accuracy was investigated for Galileo retroreflector panels. More than 1600 1-minute normal points were measured with varying pass geometries and laser beam incident angles. The polarization state was switched between along satellite track / across satellite track and circular polarization. No noticeable trend was found within the data proving the good manufacturing and clocking quality of the ESA panels. a spare Galileo

retroreflector panel was mounted on a tripod 32 km outside of the SLR station Graz. The panel was tilted to achieve laser beam incident angles between 0° and approx. 18° while simultaneously doing distance measurements. Within the full-rate data for incident angles larger that approx. 10° it was possible to identify several fine structures corresponding to the different columns of retroreflectors within the panel. This test provides a way to validate the Galileo panel pointing accuracy and is only possible by analyzing the fine details of mm-accuracy kHz SLR data.

12. Gravity field determination using Jacobi or energy integral methods requires precise orbit information and knowledge of the non-gravitational forces acting on the satellite which is provided by on-board GPS receivers and accelerometers respectfully. However, the literature restricts attention to energy conservation arising from Newton's second law of motion. The authors derive a new energy integral associated with near-Earth objects in the first post-Newtonian regime for general relativity and investigate if the post-Newtonian Jacobi-like integral can provide more accurate gravity field determination using ESA's Swarm mission.