Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 45 (2010) 721–732
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Improved kHz-SLR tracking techniques and orbit quality analysis for LEO missions

W. Hausleitner [a,*], G. Kirchner [a], S. Krauss [a], J. Weingrill [a], R. Pail [b], H. Goiginger [b], D. Rieser [b]

[a] Austrian Academy of Sciences, Space Research Institute, 8042 Graz, Austria
[b] Graz University of Technology, Institute of Navigation and Satellite Geodesy, 8010 Graz, Austria

Received 27 March 2009; received in revised form 13 November 2009; accepted 17 November 2009

Abstract

Satellite gravity field missions such as CHAMP, GRACE and GOCE are designed as low Earth orbiting spacecraft (LEO) with orbit heights of about 250–500 km. The challenging mission objectives require a very precise knowledge of the satellite orbit position in space. For these missions precise orbit information is typically provided by GPS satellite-to-satellite tracking (SST) observations supported by satellite laser ranging (SLR).

The role of SLR is primarily devoted to serve as an independent tracking instrument used to calibrate and validate the on-board GPS flight receiver. However, the very limited visibility of LEOs from SLR ground stations together with the accordingly high angular rates necessary for the laser mounting to follow the satellite make it more difficult to track LEO missions. At the Observatory Graz–Lustbühel, the Space Research Institute of the Austrian Academy of Sciences operates a very novel SLR facility which was continuously upgraded during the recent years, and is today the only station worldwide capable to operate at kHz-firing rates. The activities presented here focus on a number of hardware upgrades and methodical improvements at the SLR station Graz aiming for a faster and more reliable target acquisition. These include upgrades of laser tracking algorithms as well as a redesign of the laser detection package in particular for LEO spacecraft. These improvements allow an extension of the measurement durations and thus increase the number of observations per pass. As a result we are able to raise the normal point accuracy as well as the overall system performance for LEO tracking. Improvements of the pointing accuracy and the range gate control system lead to a data quantity raise of about 5%.

Another task addresses both a geometric and dynamic arc comparison of SLR derived orbits with GPS SST orbit solutions. In the case of CHAMP, the resulting one-way SLR range residuals are in the order of a few centimetres. This allows to draw conclusions on the accuracy of orbit solutions. In order to evaluate the performance of this technique for the upcoming GOCE mission, investigations are carried out in an analogous manner based on simulated GOCE SLR observations.

In this study, it is demonstrated that satellite laser ranging, in particular with high-rate tracking capabilities and low orbit optimizations, offers a valuable tool for orbit validation purposes.

Keywords: Satellite laser ranging; Low earth orbit; Orbit determination

1. Introduction

The Earth's gravity field is in the focus of attention of several presently operating satellite missions, which provide valuable mission data for the scientific community. CHAMP was launched in 2000 and provides a sufficiently long series of observations to resolve long-term variations

* Corresponding author.
E-mail addresses: walter.hausleitner@oeaw.ac.at (W. Hausleitner), georg.kirchner@oeaw.ac.at (G. Kirchner), sandro.krauss@oeaw.ac.at (S. Krauss), joerg.weingrill@oeaw.ac.at (J. Weingrill), roland.pail@tugraz.at (R. Pail), h.goiginger@tugraz.at (H. Goiginger), daniel.rieser@tugraz.at (D. Rieser).

0273-1177/$36.00 © 2010 Published by Elsevier Ltd. on behalf of COSPAR.
doi:10.1016/j.asr.2009.11.016

primarily in the magnetic field, in the gravity field and within the atmosphere (Rummel et al., 2002).

GRACE-A/B is a tandem mission launched in 2002 with the purpose of collecting data to improve the estimation of the long-term mean and temporal variability of the gravity field (Bettadpur, 2003).

The GOCE mission was launched on March 17, 2009 and is based on a sensor fusion concept: satellite-to-satellite tracking (SST) in the high-low mode using the GPS system, and satellite gravity gradiometry (SGG) consisting of six highly sensitive accelerometers. The GOCE mission is presently in its commissioning and calibration phase and will start the operation phase in September 2009. The GOCE mission (Drinkwater et al., 2006) is designed as a drag-free system using ion thrusters for a continuous compensation of the effects of non-gravitational forces such as atmospheric drag and solar radiation pressure. The drag-free control system is in particular outlined in Canuto et al. (2002).

All three missions are LEOs and have one tracking backup instrument in common: laser retro-reflectors (LRRs). A LRR is a corner-cube array capable of reflecting laser pulses back along the incident light path. The LRR allows acquisition of a supplementary data set of satellite laser ranging observations by the existing satellite laser ranging (SLR) ground network as a backup for precise GPS based orbit determination. It is thus an independent tracking instrument eminently applicable to calibrate and validate the on-board GPS based tracking system.

There are two applications which are relevant in using SLR observations for gravity field missions. First, the fit of SLR measurements to a reference orbit serves as an independent assessment of the orbit quality (König et al., 2003), and second, the quality of the gravity field model solution can be assessed. In this work, we concentrate on the first task.

However, there are several major difficulties to track LEO satellites as compared to those at higher altitudes. As a consequence of the low altitude, both fewer and shorter passes will be visible, significantly limiting the achievable quantity of ranging observations. The resulting high angular velocity of laser telescope mounting necessitates the usage of improved mount electronics and tracking software. Fig. 1 shows one year tracking statistics including all CHAMP passes tracked in 2008. This clearly reveals that not even a quarter of the 40 SLR stations worldwide is able to routinely track extreme LEOs. Orbit simulation studies show that only one or two GOCE passes per day will be visible from Graz. Furthermore, daytime tracking for such extreme LEOs requires an orbit prediction accuracy of better than 50 m.

Due to the date of launch in March, the GOCE satellite is in daylight in the northern, and in the Earth's shadow on the southern hemisphere. First passes have therefore been tracked by SLR stations south of the equator only (Yarragadee (AUS), San Juan (AR), Mt. Stromlo (AUS)) and no successful tracking activity from the northern station was reported up to now. This is due to the fact that the orbit predictions turned out to be significantly less accurate than the specified 50 m, at least at the time when applied for tracking. Some effort is now spent to improve this accuracy, and to provide more frequent updates of orbit predictions. ESA is currently providing a set of three predictions per day for GOCE. Additionally, the Astronomical Institute of University of Berne (AIUB) is also calculating and distributing GOCE predictions twice per day. These proved to be quite accurate, even for the non-drag-free mode of GOCE and the tracking conditions have improved significantly in the mean time. However, when the GOCE mission starts its measurement operation phase in September 2009, the day/night configuration will invert. The tracking stations on the northern hemisphere may then expect a much better SLR tracking efficiency.

For the investigations presented in this work, we use real CHAMP orbital data and SLR measurements and present

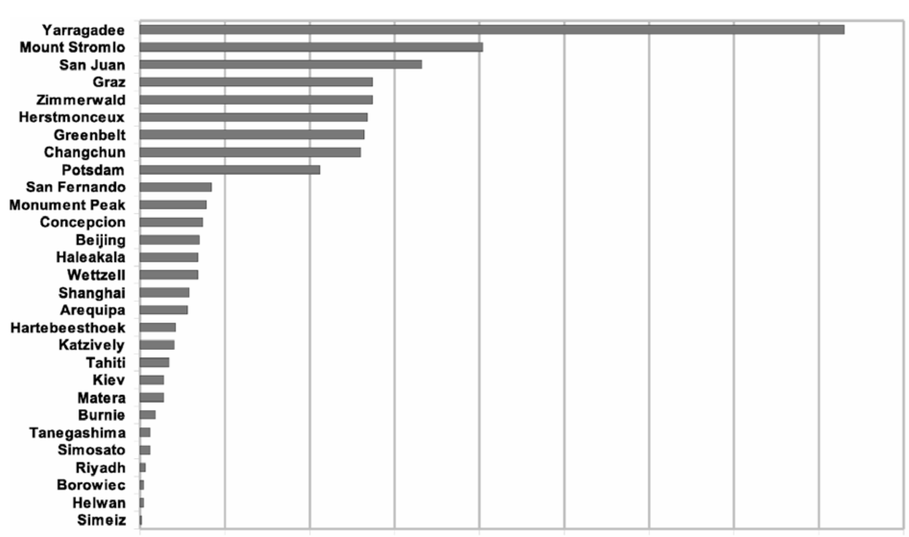

Fig. 1. Number of CHAMP passes observed by the most productive SLR stations in 2008.