Using SLR observations to Low Earth Orbiting satellites to scale neutral thermospheric density values

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Motivation

Atmospheric drag is the major non-gravitational perturbation acting on Low Earth Orbiting (LEO) satellites at altitudes up to about 1000 km. The drag depends, among other parameters, on the neutral density of thermosphere that is usually provided by empirical and physical models.

Empirical models have been derived since 1961 using such observations as mass spectro-meter, incoherent scatter radar, orbital data (satellite acceleration from precise orbit determination), accelerometer data from CHAMP, GRACE, GOCE and Swarm missions.

Knowledge on the density of the Earth’s thermosphere and exosphere is a prerequisite for planning satellite missions, precise orbit determination (POD), orbit and re-entry prediction, collision avoidance of artificial satellites orbiting the Earth at altitudes below 1000 km.

This poster shows the capability to calibrate thermospheric density values using Satellite Laser Ranging (SLR) observations of LEO satellites at altitudes between 248 and 425 km. In particular, time series of scaling factors of the thermospheric density provided by five empirical models (CIRA86, NRLMSISE-00, JB2008, DTM2013, and CH-Therm-2018) derived using SLR observations to three spherical LEO satellites (ANDE-P, ANDE-C and SpinSat) at the periods of low (August 2009 to March 2010) and high (January to March 2015) solar activity are presented (see Fig. 2 and 3).

The method used – orbit analysis approach

Atmospheric drag \( d \) is the major non-gravitational perturbation acting on LEO satellites and significantly depends on the thermospheric neutral density \( \rho \),

\[
d = -\frac{\rho V_{rel} V_0}{2 f_j \pi} dA
\]

where \( dA \) is the ratio of the effective cross-sectional area of the satellite to its mass (known),

\( \rho \) is the thermospheric density (based on the prior mentioned models),

\( V_{rel} \) is the relative velocity of the satellite w.r.t. the atmosphere (computed from POD using Horizontal Wind Model 2014 (HW14)),

\( V_0 \) is the drag unit vector (computed from POD).

The scaling factor \( f_j \) scales the thermospheric density values computed from different empirical models and is estimated from the analysis of SLR observations to spherical LEO satellites.

Our approach is based on a reduced-dynamic POD of the selected spherical satellites using the DGFI Orbit and Geodetic parameter estimation Software (DGOS). All a priori models used in the POD are based on the recommendations of the IERS Conventions 2010. More details on the applied POD approach are given in Panetta et al. (2018), more results are discussed in Rudenko et al. (2018).

Parameters estimated at each orbital arc:

- initial state vector,
- one scaling factor of the solar radiation pressure perturbing acceleration,
- one scaling factor of the Earth albedo and infrared radiation pressure perturbing acceleration,
- one scaling factor of the empirical accelerations in along- and cross-track direction (sine- and cosine-term),
- multiple scaling factors \( f_j \) of the thermospheric neutral density values (e.g., every 6/12 h).

Satellites used and their main characteristics

In order to obtain reliable scaling factors, SLR observations to LEOs with a spherical shape (for details see Tab. 1) are used in the following analysis.

Results: estimated scaling factors of thermospheric density values

Figure 2: Scaling factor \( f_j \) estimated from SLR observations to ANDE-P from 16 August 2009 to 3 October 2009 (left) and to ANDE-C from 16 August 2009 to 26 March 2013 (right). The ANDE-C data analysis indicates a trend.

Figure 3: Scaling factor \( f_j \) estimated from SLR observations to SpinSat from 29 December 2014 to 29 March 2015 (left) and to ANDE-P from 16 August 2009 to 30 September 2009 (right).

Summary

The mean values and standard deviations of the thermospheric density scaling factors of each thermospheric model (the wind model HW14 is included) estimated using SLR observations to each of the three satellites at the given time spans are summarized in Tab. 2.

Table 2: Mean values and standard deviations of the estimated thermospheric density scaling factors.

Conclusions and outlook

- SLR observations are sensitive to variations in the thermospheric density.
- Time series of scaling factors of thermospheric density values provided by the five empirical models CIRA86, NRLMSISE00, JB2008, DTM2013, and CH-Therm-2018 (Xiong et al., 2018) have been derived using SLR observations to three spherical LEO satellites (ANDE-P, ANDE-C, and SpinSat) at periods of low (August 2009 to March 2010) and high (January to March 2015) solar activity.
- The scaling factors of thermospheric density derived from SLR observations of satellites ANDE-P and ANDE-C agree well within the standard deviations for the overlapping period.
- Scaling factors of CIRA86, NRLMSISE00, and JB2008 models change depending on the level of solar activity. These models overestimate the thermospheric density values at periods of low solar activity and slightly underestimate them at periods of high solar activity.
- The CH-Therm-2018 model underestimates the thermospheric density and provides the largest scatter of estimated scaling coefficients among the model tested.
- The used satellites are difficult to track due to their high angular velocity. Therefore, we stress an importance of dense tracking of such satellites in the future to get reliable results.

References