Estimation of scaling factors of thermospheric density provided by empirical models using SLR observations to Low Earth Orbiting satellites

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Introduction

The neutral density of the thermosphere is one of the key parameters used, in particular, to compute atmospheric drag acting on the Earth's orbiting satellites and objects at altitudes below 1000 km. Various empirical and physical models of the thermospheric neutral density have been developed since 1961. However, the thermospheric density computed using various up-to-date models significantly differs for the same time and position (Figure 1).

A new method (Panetta et al., 2018) has been developed at DFGI-TUM to estimate scaling factors of the integrated thermospheric density using Satellite Laser Ranging (SLR) observations to spherical Earth orbiting satellites, in combination with a full precise orbit determination. In this method, the total drag coefficient C_F (see Eq. (1)) is computed using theSentman model by averaging over all thermospheric species.

Using this approach, we have estimated scaling factors of the thermospheric density provided by the CIRA96, NRLMSISE00, JB2008, DTM2013 and CH-Therm-2018 (Xiong et al., 2018) models using SLR observations to three spherical satellites, CH-Therm-2018 is based on 9-year accelerometer measurements from the CHAMP satellite from August 2000 to July 2009 when it flew at an altitude range between 460 and 310 km.

SLR observations used in this study: ANDE-P from 16 August 2009 to 3 October 2009, ANDE-C from 16 August 2009 to 26 March 2010 and SpinSat from 29 December 2014 to 29 March 2015, i.e. at the periods of low and high solar activity and the altitude range from 300 to 426 km.

Satellite Laser Ranging (SLR) observations

SLR is a geodetic tracking technique which can be used for Low Earth Orbit (LEO) precise orbit determination (POD). It provides highly accurate travel time measurements of laser pulses reflected at laser Retro-Reflector Arrays mounted on the satellite surface which have been emitted from telescopes on the Earth’s surface. Due to the high measurement precision, SLR observations are highly sensitive to any perturbing acceleration acting on the satellite.

To increase the accuracy of the estimated thermospheric density scaling factors, we use SLR observations to LEOS with a spherical shape, since, for such satellites, the errors of all parameters in Eq. (1) besides the thermospheric density are small. Therefore, for spherical satellites, the scaling factors are thermospheric density scaling factors.

In our investigation, we use the satellites Atmospheric Neutral Density Experiment 2 (ANDE-2) Pollux (P) and Castor (C), as well as the 'Special Purpose Inexpensive Satellite' (SpinSat), see Fig. 2. The satellite radii are 0.483 m (ANDE-2) and 0.558 m (SpinSat).

Approach

For the LEO POD, we model the atmospheric drag force as

\[ F = -\rho \frac{\partial v}{\partial t} \cdot \mathbf{v} \]

where \( \rho \) is the effective cross-sectional area of the satellite, \( m \) is the satellite mass, \( C_F \) is the dimensionless drag coefficient (analytically computed using a gas-Surface Interaction model, physical assumptions and other key parameters), \( \rho \) is the thermospheric density at satellite position, \( v_{rel} \) is the satellite relative velocity w.r.t. atmosphere (computed from POD), and \( \mathbf{v} \) is a unit vector.

The scaling factor \( f_\rho \), in Eq. (1) accounts for the different magnitude of the density values computed from different empirical models. We estimate the scaling factor \( f_\rho \) according to Eq. (1) with a temporal resolution of 6-12 hours depending on the amount of SLR observations available.

Our approach is based on a fully dynamic POD of the selected spherical satellites using the DFGI Orbit and Gasdynamic parameter estimation software (DOGS). 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).

Results: estimated scaling factors of thermospheric density

Figure 3: Scaling factor \( f_\rho \) estimated from SLR measurements of ANDE-P (left) and ANDE-C (right) for the time intervals given in Table 1 for the respective satellite. The ANDE-C data analysis indicates a trend.

Figure 4: Scaling factor \( f_\rho \) estimated from SLR measurements of SpinSat (left) and ANDE-C altitude (right) for the time intervals given in Table 1 for the respective satellite. Gaps in the altitude and scaling factor time series are caused by the gaps in the observations not allowing to compute a reliable orbit at these time intervals.

Table 1: Thermospheric density scaling factors computed using SLR observations for 5 models.

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<tr>
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<tbody>
<tr>
<td>CIRA96</td>
<td>0.65 ± 0.26</td>
<td>0.68 ± 0.20</td>
<td>1.04 ± 0.25</td>
</tr>
<tr>
<td>NRLMSISE00</td>
<td>0.65 ± 0.25</td>
<td>0.68 ± 0.20</td>
<td>1.05 ± 0.23</td>
</tr>
<tr>
<td>JB2008</td>
<td>0.89 ± 0.27</td>
<td>0.97 ± 0.21</td>
<td>1.11 ± 0.23</td>
</tr>
<tr>
<td>DTM2013</td>
<td>0.79 ± 0.24</td>
<td>0.83 ± 0.16</td>
<td>0.67 ± 0.13</td>
</tr>
<tr>
<td>CH-Therm-2018</td>
<td>0.97 ± 0.16</td>
<td>1.16 ± 0.30</td>
<td>0.94 ± 0.18</td>
</tr>
</tbody>
</table>

Time series of scaling factors provided for the 5 empirical models CIRA96, NRLMSISE00, JB2008, DTM2013, and CH-Therm-2018 have been derived using SLR observations to three spherical LEOS ANDE-P, ANDE-C and SpinSat at the periods of low and high solar activity.

The scaling factors derived from SLR observations to the two satellites ANDE-P and ANDE-C for the same (overlapping) period agree well within the standard deviations for all five models.

The scaling factors for CIRA96, NRLMSISE00 and JB2008 change depending on the level of solar activity. These models overestimate the thermospheric density at low solar activity and slightly underestimate it at high solar activity.

All five models indicate trends in the scaling factors estimated from ANDE-C data.

The thermospheric density provided by the CH-Therm-2018 model fits rather good to SLR observations of three satellites, since the thermospheric density of this model was scaled using the median scaling factor obtained using SLR data to ANDE-P in Xiong et al. (2018). The increased values of the scaling factors after 6 February 2010 (Fig. 3, right) are obtained at the ANDE-C altitude below 310 km (Fig. 4, right), i.e. below the validity altitude interval (310-440 km) of this model.

References


Rudenko S., Schmidt M., Bloßfeld M., Xiong C., Lühr H.: Calibration of empirical models of thermospheric density using Satellite Laser Ranging observations to Near-Earth orbiting spherical satellites, IAG Symposium, DOI: 10.1007/978-3-319-48340-6_40, 2018.


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