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Estimation of scale factors from SLR observations to LEO satellites for the thermospheric density computed from empirical and physical models

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Motivation and method description

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 observations, while physical models are developed by solving fluid equations to express neutral density using thermodynamic principles.

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.

We present time series (Fig. 5-6) of scaling factors of the thermospheric density provided by **five empirical models** (CIRA86, NRLMSISE00, JB2008, DTM2013, and CH-Therm-2018) and **TIEGCM physical model.** The time series are derived using **Satellite Laser Ranging (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 and altitudes between 248 and 425 km.

Our approach is based on a reduced-dynamic POD of the selected spherical satellites using the DGFI Orbit and Geodetic parameter estimation Software (DOGS). All a priori models used in the POD are based on the recommendations of the IERS Conventions 2010. We analyze atmospheric drag acting on a LEO satellite and estimate, among other parameters, **scaling factor that scales the thermospheric density** values computed from different empirical models from the analysis of SLR observations to the satellite. Due to the correlation between the atmospheric drag and the total drag coefficient, the drag coefficient is computed analytically using a gas-surface interaction model, namely Sentman model. More details on the applied POD approach are given in **Panzetta et al. (2018),** some results are discussed also in **Rudenko et al. (2018).**

Comparison of the thermospheric density provided by the models

The thermospheric density provided by various empirical and physical models differs. Thus, NRLMSISE00 and TIEGCM models provide **different patterns** for the day and night sides of the Earth's atmosphere (Fig.1 and 2). Also **the magnitude of the thermospheric density** computed using these models differs for various satellites. More significant differences are obtained for ANDE-C (Fig. 3), as compared to SpinSat (Fig.4).

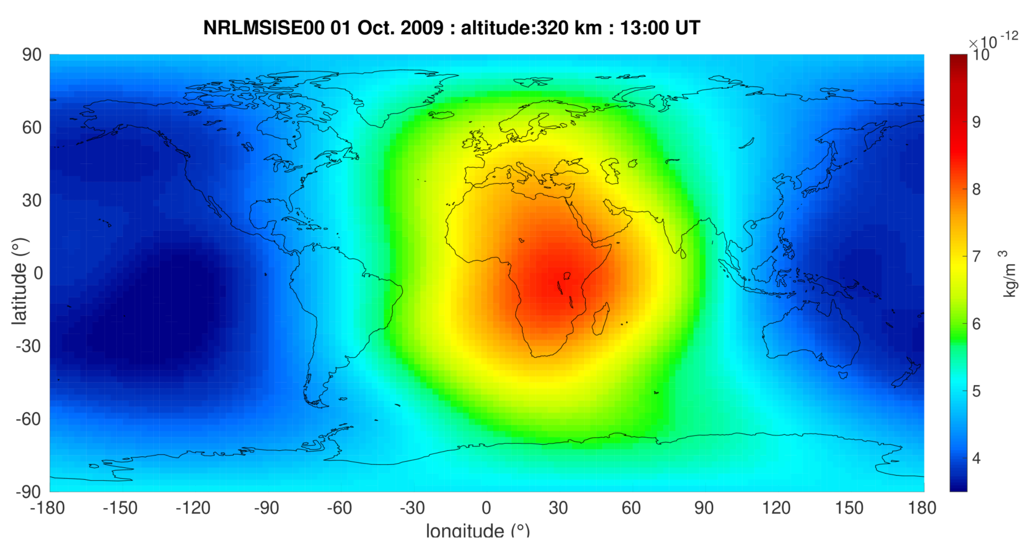

Figure 1. Thermospheric density computed for October 1, 2009, 13:00 UTC at altitude of 320 km using the NRLMSISE00 model.

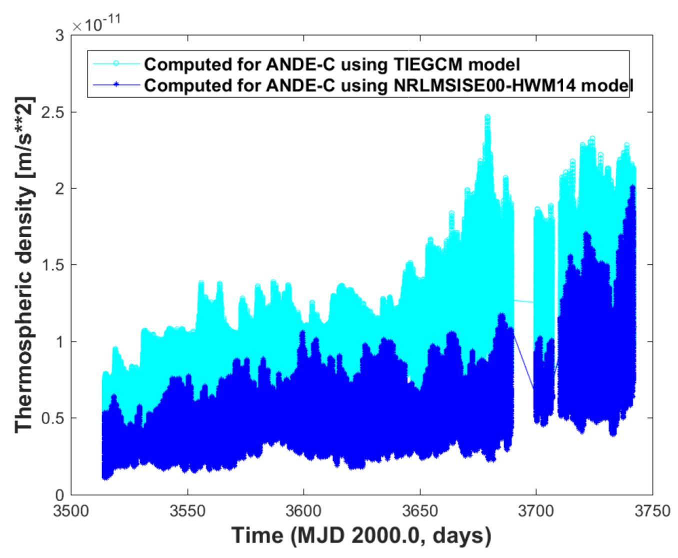

Figure 3. Thermospheric density computed for the ANDE-C positions from 16 August 2009 to 26 March 2010 using the TIEGCM and NRLMSISE00 models.

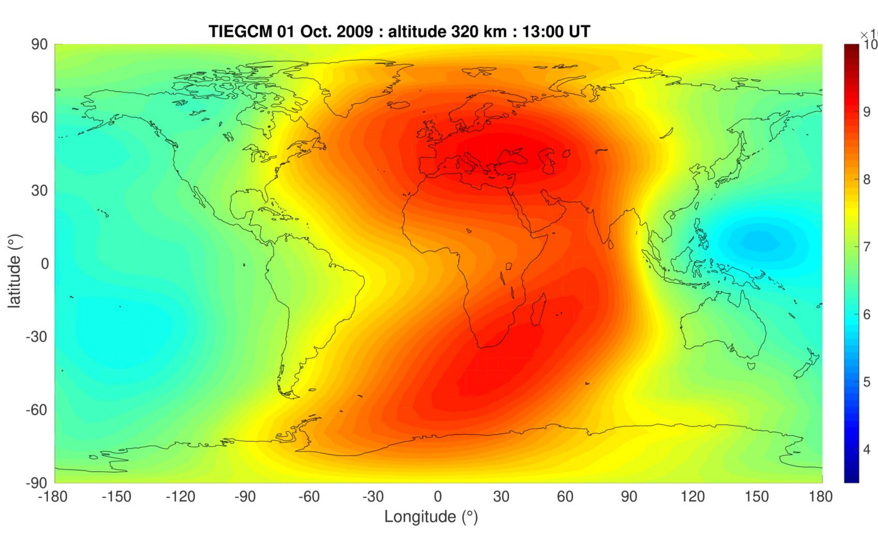

Figure 2. Thermospheric density computed for October 1, 2009, 13:00 UTC at altitude of 320 km using the TIEGCM model.

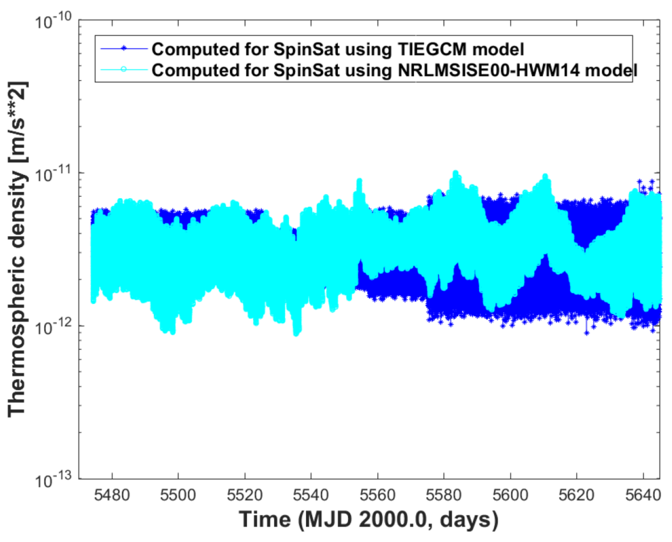

Figure 4. Thermospheric density computed for the SpinSat positions from 29 December 2014 to 29 March 2015 using the TIEGCM and NRLMSISE00 models.

Satellites used and their main characteristics

Satellite name	Diameter [m]	Mass [kg]	A_{ref} / m [m^2 / kg]	CoM [m]	Drag coefficient [-]	Initial altitude [km]	Inc. [deg.]
ANDE-P	0.483	27.442	0.00667	0.224	2.115 ± 0.002	350	51.6
ANDE-C	0.483	47.450	0.00386	0.225	2.115 ± 0.002	350	51.6
SpinSat	0.558	52.650	0.00465	0.264	2.126 ± 0.002	425	51.6

Table 1: Parameters of the satellites used in this study.

Acknowledgements: This research was partly supported by the German Research Foundation (DFG) within the project "Interactions of low-orbiting satellites with the surrounding ionosphere and thermosphere (INSIGHT)" in the framework of the Special Priority Program (SPP) 1788 „Dynamic Earth" and by BMWi/DLR within the project "Operational prototype for the determination of the thermospheric density on the basis of a coupled thermosphere-ionosphere model (TIK)".

Results: estimated scaling factors of thermospheric density values

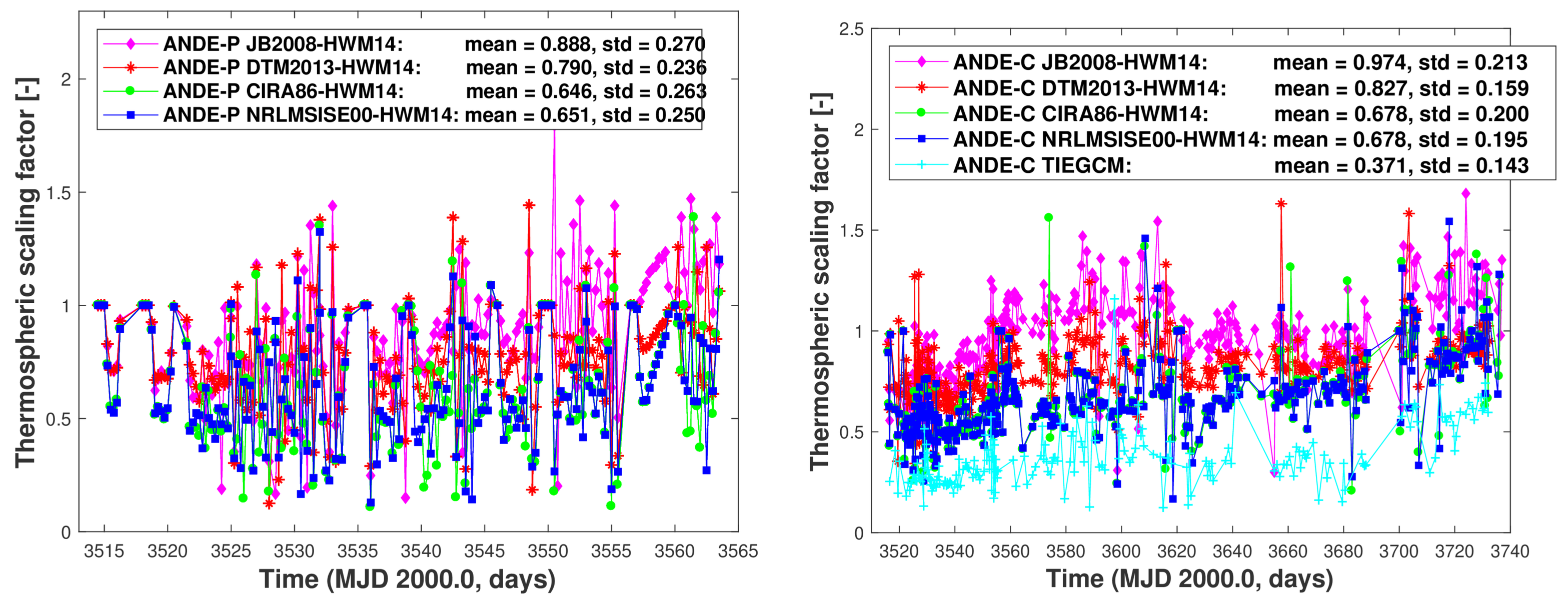

Figure 5: Scaling factor of thermospheric density for various models estimated from SLR observations to ANDE-P from 16 August 2009 to 3 October 2009 (left) and to ANDE-C from 16 August 2009 to 26 March 2010 (right), modified from Rudenko et al., 2018.

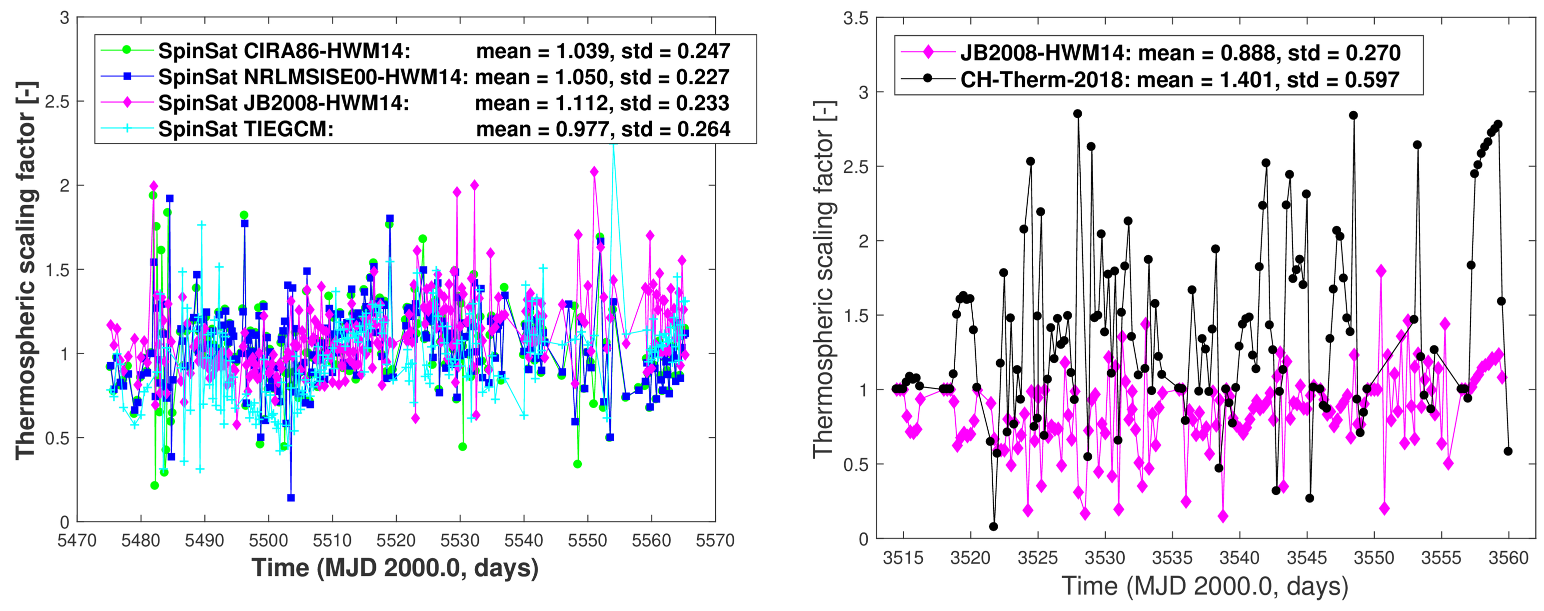

Figure 6: Scaling factor of thermospheric density for various models estimated from SLR observations to SpinSat from 29 December 2014 to 29 March 2015 (left) and to ANDE-P from 16 August 2009 to 30 September 2009 (right), modified from Rudenko et al., 2018.

Summary

The mean values and standard deviations of the thermospheric density scaling factors of each thermospheric model (the wind model HWM14 is included) estimated using SLR observations to each of the three satellites at the given time spans are summarized in Tab. 2.

Thermospheric model	ANDE-P 16.08.09 – 03.10.09, low solar activity 248 < h < 369 km	ANDE-C 16.08.09 – 26.03.10, low solar activity 297 < h < 350 km	SpinSat 29.12.14 – 29.03.15, high solar activity 393 < h < 425 km
CIRA86	0.65 ± 0.26	0.68 ± 0.20	1.04 ± 0.25
NRLMSISE00	0.65 ± 0.25	0.68 ± 0.20	1.05 ± 0.23
JB2008	0.89 ± 0.27	0.97 ± 0.21	1.11 ± 0.23
DTM2013	0.79 ± 0.24	0.83 ± 0.16	—
TIEGCM	—	0.37 ± 0.14	0.98 ± 0.26
CH-Therm-2018	1.40 ± 0.60	—	—

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

Conclusions

- **SLR observations are sensitive** to variations in the thermospheric density.
- **Time series of scaling factors of thermospheric density values** provided by five empirical models (CIRA86, NRLMSISE00, JB2008, DTM2013, and CH-Therm-2018 (Xiong et al., 2018)) and TIEGCM physical model 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 TIEGCM model** overestimates the thermospheric density during the period of low solar activity and provides thermospheric density that fits to the SLR observations at the period of high solar activity rather good.

References

- Panzetta F., Bloßfeld M., Erdogan E., Rudenko S., Schmidt M., Müller H. (2018) ***Towards thermospheric density estimation from SLR observations of LEO satellites: a case study with ANDE-Pollux satellite***, J Geodesy, 93(3), 353–368, DOI:10.1007/s00190-018-1165-8.
- Rudenko S., Schmidt M., Bloßfeld M., Xiong C., Lühr H. (2018) ***Calibration of empirical models of thermospheric density using Satellite Laser Ranging observations to Near-Earth orbiting spherical satellites***, In: (Eds.), In: Freymueller J., Sánchez L. (eds). International Association of Geodesy Symposia, DOI:10.1007/1345_2018_40.
- Xiong C., Lühr H., Schmidt M., Bloßfeld M., Rudenko S. (2018) ***An empirical model of the thermospheric mass density derived from CHAMP satellite***, Ann Geophys, 36(4): 1141-1152, DOI:10.5194/angeo-36-1141-2018.

2019 Living Planet Symposium, 13-17 May 2019, Milan, Italy