THE SEMI-EMPIRICAL THERMOSPHERE MODEL DTM2012

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ABSTRACT

The Drag Temperature Model (DTM) is a semi empirical model describing the temperature, density and composition of the Earth's thermosphere, which is mainly developed for orbit computation.

The total density data used in the latest version, DTM2012, includes high-resolution CHAMP and GRACE data. DTM2012 was constructed with the data used in DTM2000 as well, but with an improved algorithm. The bias and precision of the model is evaluated by comparing to the observations according to a metric, which consists of computing mean, rms and correlation. This evaluation shows that DTM2012 is the most accurate model for the data that were assimilated. Comparison to independent density data shows that it is also the most accurate model overall and a significant improvement over DTM2009 and JB2008 under all conditions.

1 INTRODUCTION

Thermosphere models are, besides their use in atmospheric studies, necessary to calculate the atmospheric drag force in satellite orbit computation. They predict temperature and composition as a function of the location (altitude, latitude, longitude, local solar time), solar and geomagnetic activities, and day-of-year. The latest version of the Drag Temperature Model, DTM2012, is presented in this paper and compared with the COSPAR reference model JB2008 [1], as well as with the last published version of DTM, DTM2009 [2].

DTM2012 and the models evaluated in this paper are constructed by fitting to the underlying density database as good as possible in the least-squares sense (i.e. semi-empirical model). They reproduce the mean climatology of the thermosphere. The spatial resolution of these models is of the order of thousands of kilometers. All density variations with smaller scales are sources of geophysical noise. The temporal resolution is limited by the solar and geomagnetic activity indices, 1 day and 3 hours, respectively.

DTM2012 was developed in the framework of the Advanced Thermosphere Modelling and Orbit Prediction project (ATMOP), which is a European Union 7th Framework project. The main objective of the ATMOP research project is to update the DTM thermosphere model and to develop an operational and a near-real-time version.

2 DATA AND MODEL

2.1 Total Density Data Sets

High-resolution total neutral densities were derived from accelerometer measurements on the Challenging Mini-Satellite Payload (CHAMP) in the altitude range 450-250 km, and the Gravity Recovery and Climate Experiment (GRACE) near 490 km altitude using the methodology described in [3]. The CHAMP data set used in this study covers the period 20/05/2001 through 2/9/2010, i.e. up to 2 weeks before atmospheric re-entry. GRACE data cover the period 01/03/2003 through 31/12/2010. Both data sets cover solar cycle maximum to minimum conditions. CHAMP (GRACE) 24-hour local solar time sampling is achieved approximately every four (five) months. The accelerometers provide high-resolution measurements from which densities are inferred with 80 and 40 km in-track resolution for CHAMP and GRACE, respectively. The Atmosphere Explorer satellites (AE; 1973-1978) carried the Miniature Electro Static Accelerometers (MESA). The density data are made available by NASA's National Space Science Data Center, with in-track resolution of these measurements being approximately 120 km.

Total densities have also been inferred from Stella and Starlette orbit analyses, thanks to the accurate laser ranging data. These cannonball-shaped geodetic satellites are in a 96° inclination and near-circular orbit at approximately 813 km altitude, and 49° inclination slightly eccentric orbit (e=0.02) with a perigee altitude of 800 km, respectively.

Precise orbit determination of Deimos-1, a small Earth observation satellite in a circular Sun-synchronous orbit (LST approximately 10:40/22:40) at about 680 km, provided density data for 2010-2011.

Besides the new total density data described above, all the mass spectrometer data from the AE satellites and the Dynamic Explorer 2 satellite have been assimilated (temperature, and O, He and N_2 partial densities), as well as OGO6 temperatures. The CACTUS total densities have been used too. All data used in DTM2012 is listed in Tab. 1. For more details on the historic datasets, the reader is referred to [4].

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Table 1. The data used in the construction of DTM2012

Data	Timeframe
CHAMP	05/2001 - 08/2010
GRACE	01/2003 - 12/2010
Starlette & Stella	01/1994 - 12/2010
Deimos-1	03/2010 - 09/2011
CACTUS	07/1975 - 01/1979
OGO6	06/1969 - 08/1975
DE-2 (T, He, O, N2)	08/1981 - 02/1983
AE-C (N2)	01/1974 - 04/1977
AE-E (T, He, O)	12/1975 - 05/1981

2.2 DTM Model Algorithm

The representation of the total density in the altitude range 120-1500 km is achieved by summing the contributions of the main thermosphere constituents (N_2, O_2, O, He, H), under the hypothesis of independent static diffuse equilibrium. The height function $f_i(z)$ per constituent i is the result of the integration of the differential equation of diffusive equilibrium; partial densities specified at 120 km altitude are propagated to higher altitudes employing this function. The exospheric temperature and the partial density variations as a function of the environmental parameters L (latitude, local solar time, solar flux, and geomagnetic activity) are modeled by means of a spherical harmonic function $G(L)$. The total density ρ at altitude z is then calculated as follows:

$$\rho(z) = \sum_i \rho_i(120km) f_i(z) \exp(G_i(L))$$

DTM2012 models the exospheric temperature and the atmospheric constituents each with up to 50 coefficients. The function G is used to describe periodic and non-periodic variations. Periodic variations are defined as annual and semi-annual terms, as well as diurnal, semidiurnal and terdiurnal terms. The non-periodic terms consist of constant zonal latitude coefficients, and coefficients relating solar and geomagnetic activity to temperature and density.

3 MODEL EVALUATION

The DTM2012, JB2008, and DTM2009 models are compared with total density data in the following sections. The models are evaluated by computing the mean and RMS of the density ratios and residuals, which we have defined as 'observed-to-calculated' (O/C) and 'observed minus calculated' (O-C). They reflect relative and absolute precision of the models, respectively. A model bias, i.e. the mean, is most damaging in orbit extrapolation because it causes position errors that increase with time. The RMS represents a combination of the ability of the model to reproduce the observed variations and the geophysical and instrumental noise in the observations. The correlation coefficients R are also computed.

Only the results for CHAMP and GRACE, and for the independent datasets from the US Air Force, are presented separately.

3.1 CHAMP and GRACE

The mean, RMS and the correlation coefficients are computed per year for these data sets. The results are shown in Figs. 1-6. The mean values per year are displayed, and the mean and rms taking all years is printed for each model.

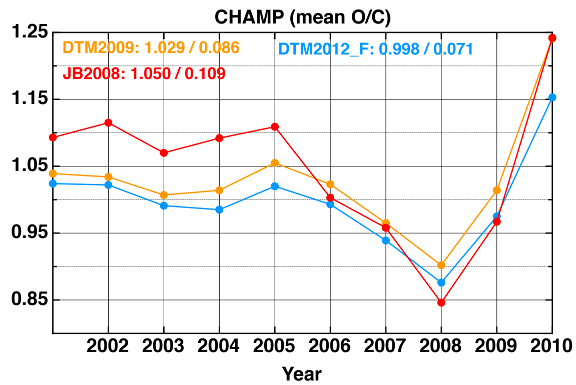

Figure 1. Model bias with respect to CHAMP, per year.

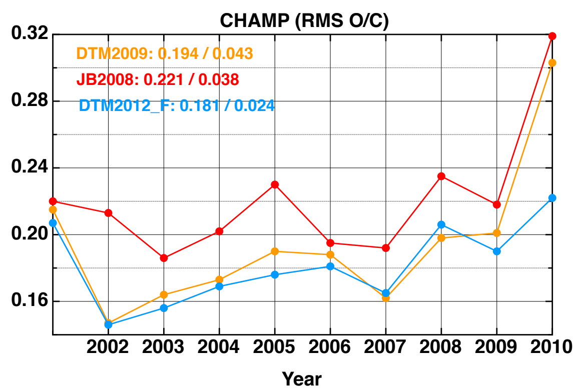

Figure 2. RMS of the CHAMP O/C, per year.

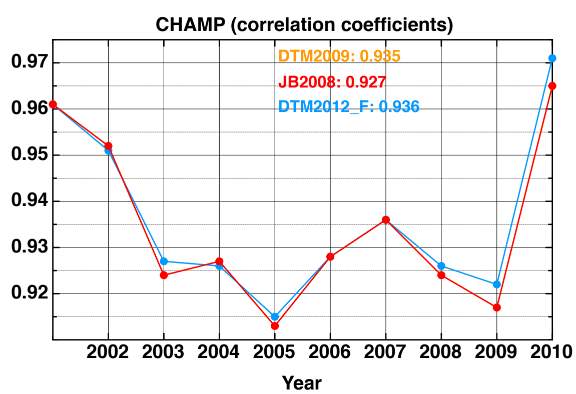

Figure 3. Model correlations with CHAMP, per year.

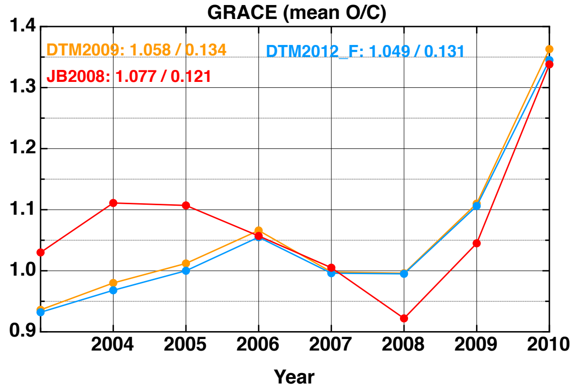

Figure 4. Model bias with respect to GRACE, per year.

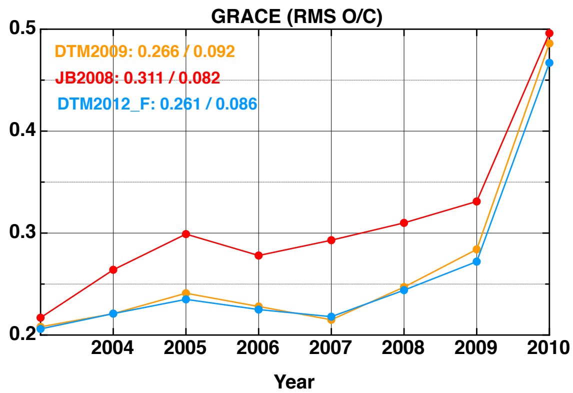

Figure 5. RMS of the GRACE O/C, per year.

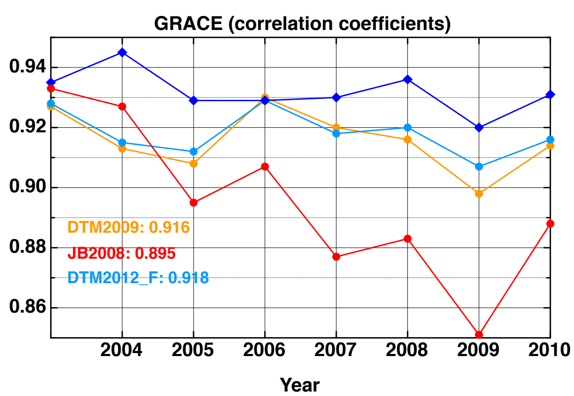

Figure 6. Model correlations with GRACE, per year.

The figures clearly show that DTM2012 is a significant improvement over DTM2009, and that it is the most precise model when comparing to CHAMP and GRACE. Note that these data were assimilated in DTM2012.

3.2 US Air Force mean and HASDM densities

The mean EDR (Energy Dissipation Rate) densities shown in the Figs. 7-9 were not assimilated in DTM2012; they were in JB2008. The accurate daily-mean data, of 13 satellites, were kindly provided by Bruce Bowman of US Space Command. The mean densities were then averaged per year using all 13 satellites.

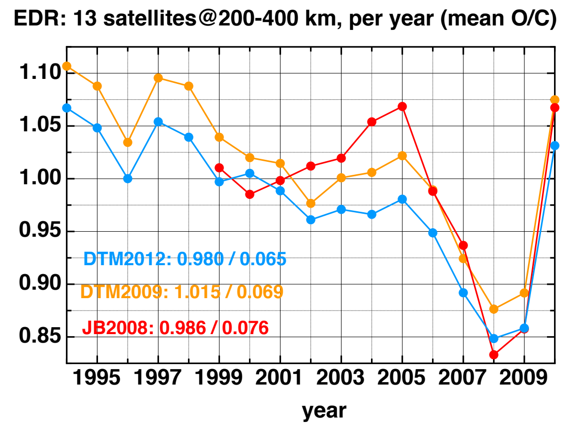

Figure 7. Model bias with respect to EDR data, per year.

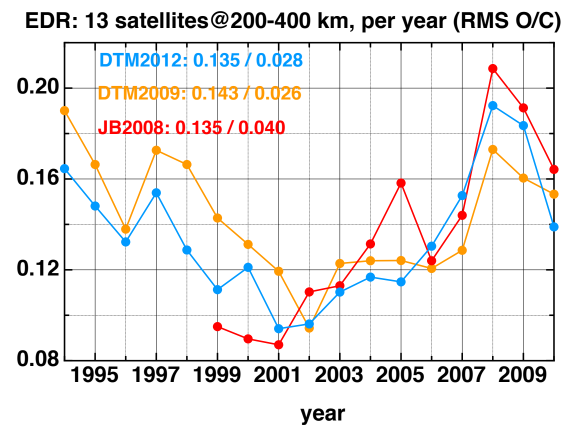

Figure 8. RMS of the EDR O/C, per year.

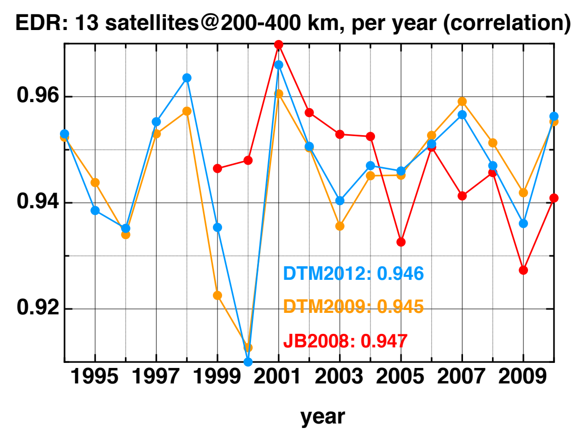

Figure 9. Model correlations with EDR data, per year.

DTM2012 is as accurate as JB2008 when compared to the EDR data, which were not used. The only problematic year appears to be 2000, when the correlation drops to significantly (but is still 0.91).

A second independent density data source from the US Air Force (courtesy Bruce Bowman) is the operational model HASDM (High Accuracy Satellite Drag Model [5]), which is corrected in near real-time from observed drag effects using radar tracking data. The densities along the obit of ESA's GOCE satellite at an average altitude of 270 km were provided for the years 2010 and 2011. The results are listed in Tab. 2.

Table 2. Model comparisons with HASDM@GOCE densities for 2010, 2011 and 2012.

(2010)	<O/C>	RMS O/C	RMS O-C, g/cm^3
JB2008	1.093	0.160	3.44E-15
DTM2009	1.089	0.156	3.24E-15
DTM2012	1.004	0.114	2.69E-15
(2011)			
JB2008	1.143	0.193	6.35E-15
DTM2009	1.101	0.152	5.10E-15
DTM2012	1.014	0.109	4.07E-15
(2012)			
JB2008	1.207	0.246	8.93E-15
DTM2009	1.090	0.150	6.47E-15
DTM2012	1.004	0.111	5.39E-15

The results for this lowest orbit are best by far with DTM2012, which is unbiased and has the smallest RMS'. The relative precision is rather constant over the three years, but the effect of the increasing density as the solar cycle progresses to its maximum can be seen in the growing values of the RMS of the O-C residuals (right column). This dataset has not been used in DTM or JB2008, and as such gives an impartial assessment of the models.

4 SUMMARY AND CONCLUSION

The new version of the DTM thermosphere model, DTM2012, has been constructed using mass spectrometer and high-resolution total density data inferred from accelerometers onboard CHAMP and GRACE. The model does not depend on solar activity measurements from space (like JB2008), which makes its use easier and more robust; the solar radio flux F10.7 is used, together with the planetary geomagnetic index am.

Comparison with (independent) density data showed that it is significantly more accurate than its predecessor, DTM2009, and also more accurate than the COSPAR reference model for drag JB2008. Fig. 10 displays the model bias per year for the main data sets, which are at different altitudes in the 200-800 km range; no significant model bias is detected as a function of altitude.

In the framework of the 7th framework programme ATMOP another update of the model will be done in 2013, and DTM2103 will be released in the fall of 2013. Improvements are expected through data assimilation of the GOCE densities mainly, but also some other new data sets, as well as by improving the storm-time modeling with new geomagnetic indices developed within the project.

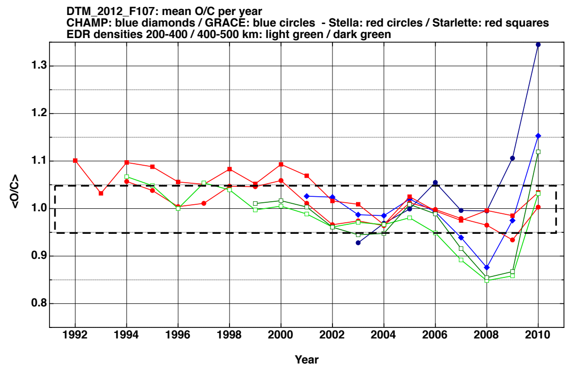

Figure 10. DTM2012 bias with respect to the main density data sets, per year.

Acknowledgements

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