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Solar Cycle Variability of the Thermospheres of Mars and Earth

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Abstract

This paper comparatively examines long-term variations in the thermospheres of Mars and Earth, from the solar maximum of 2002-2003 to the deep solar minimum of 2009-2010. Data employed include densities and exosphere temperatures derived from orbital drag analyses of the Mars Odyssey (MO) satellite for Mars, and accelerometer measurements on the CHAMP satellite for Earth. Derivation of thermosphere densities are relatively straightforward for Earth, but the Mars thermosphere data require precise orbit determination techniques and separation of such factors as solar radiation pressure and various nuances of the gravity field, as well as accounting for possible density variations connected with dust storms. Delineation of solar cycle variability in planetary thermospheres serves the important role of constraining energetics balances in first-principles general circulation models [1,2,3].

1. Introduction

Quantifying and understanding comparative and contemporaneous changes in the exospheres of Earth and Mars to changes in solar flux serve to constrain comparative planetary thermosphere simulations and may help resolve existing uncertainties in thermal balance processes, particularly CO_2 cooling [1,2,3,5]. Such studies have been performed using densities derived from precise orbit determination of the Mars Global Surveyor (MGS) spacecraft, and with respect to both 27-day solar rotation variations during 2002 and longer-terms solar cycle variations between 1999-2005 [3,4,5]. However, solar activity reached a deep solar minimum in 2009, and it is of interest to ascertain how the exospheres of Mars and Earth responded to this unusual depression in solar flux. Since MGS data are not available during this period, we perform a similar analysis using precise orbit determination of MO, and analyze the response of Mars' exosphere to long-terms solar flux changes extending from 2002 through 2010. A similar analysis is contemporaneously performed for the CHAMP satellite at Earth, and results are compared.

The solar minimum conditions of 2008-2010 present a special challenge for this study, due to the low levels of drag on MO, which makes derivation of densities difficult even when precise orbit determination methods are used. We use the same methodology as in our previous studies for MGS, which is described in [6] and outlined briefly below.

2. Odyssey Density Derivation

We have derived mean neutral densities of Mars' upper atmosphere using estimated density scale factors derived from Mars Odyssey (MO) precise orbit computations. The accuracy of the estimated drag scale factors depends on the quality of the trajectory determination and the tracking system. The former requires accurate gravity field and radiation pressure models, while the latter requires accurate and evenly distributed tracking data. Leakage of non-density related errors into the estimated drag scale factors takes place if these conditions are not met. A second concern is the drag coefficient, which models the momentum exchange between the satellite surface and the colliding particles and so affects the deduced density directly. Our modeling includes a 95x95 spherical harmonic model of the Mars gravity field, and a nine-plate macromodel (spacecraft bus, solar array and high gain antenna) to model the surface forces, including the effect of self-shadowing. MO attitude information in the form of telemetered quaternions were used to orient the macromodel in inertial space and to orient both the articulating solar array and the high gain antenna with respect to the spacecraft body. X-band Doppler and DSN tracking data were processed in arcs of four days. The adjusted parameters in each arc include the spacecraft state, and a drag scale factor and solar radiation pressure reflectivity coefficient per arc. Angular momentum desaturation maneuvers are modeled explicitly. The drag scale factor is used to scale a model density, which results in a mean density with temporal resolution of 4 days and spatial resolution limited to the MO orbital plane and altitude.

Initial results from the orbital decay analysis of MO are presented in Figure 1. Similar density derivations have been made for CHAMP at Earth (not shown). The quasi-2-year variations in density and F10.7 in Figure 1 are Mars orbital effects. The grey-shaded areas represent near-conjunction, and are characterized by more scatter in the observations. For a study focusing on long-term response to solar flux, these data can be omitted without affecting the analysis. Scatter is also seen extending from 2008-2010. This is due to the unusually low thermosphere densities during this minimum in solar activity, and the MO orbital changes are consequently more difficult to detect. The data analysis will be re-done using longer arcs of data until the variability is reduced to an acceptable level. A longer averaging period will not negatively affect the analysis or conclusions for this study, which focuses mainly on long-term change.

3. Figures

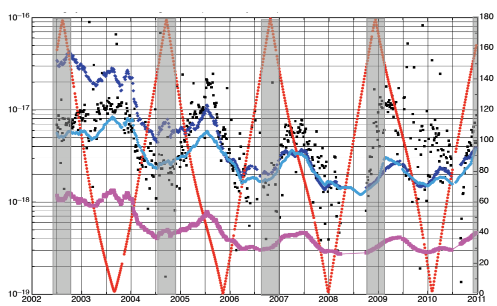

Figure 1: Mars thermosphere density (g/cm3) vs. year, 2002-2010. Black squares represent MO densities at 405 km. Blue and light blue symbols are Stewart and MarsGRAM model densities. Red dots denote the Earth-Sun-Mars angle. Magenta line denotes the mean F10.7 solar flux at Mars, and the shaded grey areas represent near-conjunction, where the Earth-Sun-Mars angle is > 150 degrees.

4. Summary and Conclusions

There are several remaining (but straightforward) steps that remain before conclusions can be drawn concerning the relative change in exosphere temperature between Mars and Earth in the descending portion of the last solar cycle, which ended in a very deep solar minimum. First, we must optimize the length of arcs employed to arrive at the results in Figure 1, arriving at an arc length that minimizes the noise due to a weak drag signal. Second, the Odyssey densities need to be converted to exosphere temperatures as we have done in previous studies [3,5]. (The corresponding exosphere temperature data have already been calculated for CHAMP.) Then a similar analysis can be conducted as in [5], with emphasis this time on the deep solar minimum of 2008-2010.

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