

## ***Interactive comment on “Density correction of NRLMSISE-00 in the middle atmosphere (20–100 km) based on TIMED/SABER density data” by Xuan Cheng et al.***

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I thank the reviewers for valuable comments and constructive critique.

Based on your comments, we need to restate the necessity and significance of revising the model. At present, researches on the revised NRLMSISE-00 model is aimed at engineering applications. For example, the accuracy of the atmospheric density of NRLMSISE-00 model cannot meet the normal operation of the satellite. Therefore, the atmospheric density of the model is modified at the orbital altitude of the satellite, at an altitude of 400~600km. At present, the research on the modification of NRLMSISE-00 density of 20-100km has not been reported, but the modification of the

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atmospheric density of the model within this height range is also very necessary. In addition, there is some error in the atmospheric density of NRLMSISE-00 output. More accurate NRLMSISE-00 atmospheric density data are needed when satellites fall into the atmosphere or when space vehicles fly in this altitude range.

Finally, all comments were carefully considered and addressed. Answers to all the questions are presented below.

(1) There is no need to improve the NRLMSISE-00 climatology to account for atmospheric waves. There is high-quality density information available throughout the middle atmosphere from meteorological analysis as well as reanalysis data sets (see NAVGEM-HA, MERRA2, ECMWF, etc.). Further, nudged GCM's provide additional information on the wave-driven variability of the neutral air density or longterm changes in the middle atmosphere (WACCM, WACCM-X etc.). Some of these data sets even allow us to resolve the day-to-day variability of the neutral air density variability due to planetary waves and tides as well as gravity waves.

Reply: I agree with the reviewer's opinions that reanalysis data can provide high-quality density information of middle atmosphere density and the numerical models (WACCM, waccm-x) can be used for numerical simulation of the variations of atmospheric density waves and long-term changes. Re-analysis data and numerical models are widely used in the field of scientific research, but re-analysis data and numerical models are less used than NRLMSISE-00 empirical models in engineering applications. In engineering applications, NRLMSISE-00 empirical model can simply and quickly output the required atmospheric data, which are why NRLMSISE-00 model is widely used in satellite orbit prediction and other engineering fields. Since the modification the atmospheric density of the NRLMSISE-00 between 20 and 100km has corresponding requirements and application scenarios, the NRLMSISE-00 model needs to be corrected.

(2) Planetary waves and tides show a strong seasonal and inter-seasonal variability. In particular, the phases of atmospheric waves are variable, causing issues using em-

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pirical climatologies for a certain atmospheric wave. This variability manifests in the occurrence of sudden stratospheric warmings, which evolve quite different from year to year. This phase variability is also an important issue for tides, which show a significant response to changes in the middle atmosphere resulting in a interday variability that cannot be covered using 60-day climatological output.

Reply: I couldn't agree with you more. The phase of atmospheric wave is variable, which is an important problem in scientific research. TIMED/SABER is limited by its own observation system, which requires 60 days to cover a 24-hour local time. In order to account for the impact of atmospheric tidal waves, the 60-day climatological output had to be considered. The correction of interday variability of atmospheric tidal phase will be added to the correction function in the subsequent study.

(3) Why correct an empirical model, which is still very good, if one has weather models that provide the neutral air density and the associated variability for free?

Reply: Compared with the numerical model, the NRLMSISE-00 model has the advantages of simple use and high calculation efficiency. Compared with other empirical models, the model has higher accuracy and is widely used in the engineering field, even if the model has been released for free for about 20 years. In the application of satellite orbit determination and orbit prediction, many experts have been carrying out research on the modification of NRLMSISE-00 model in order to obtain more accurate atmospheric density data of orbital altitude. At present, this model is typically used in the basic research (such as track prediction, aerodynamic heating, etc.) of space vehicles flying at altitudes of 20-100km. However, it is necessary to improve the accuracy of the atmospheric density data of this model so as to provide higher precision density data for relevant studies. Therefore, we need to explore some correction methods to modify the results of 20-100km to better meet the engineering requirements.

(4) Further, the reviewer is concerned about the claims of the authors that SABER represents a 'true' measure of the neutral air density. At the MLT SABER observes

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mostly CO<sub>2</sub> and converts it to an absolute neutral density assuming a volume mixing ratio, which shows also rather large errors (see Remsberg et al., 2008 and et al., 2015). The errors at the MLT of the volume mixing ratio are as high as 15-30%. This also limits the possibility to draw fundamental conclusions about the absolute density scale. Further, it is worth to consider that some a priori information in the SABER retrievals is taken from WACCM (chemical equilibrium codes)

Reply: Although the errors of CO<sub>2</sub> volume mixing ratio are as high as 15-30% in the MLT region, it can affect the accuracy of neutral air density and the accuracy of correction to a certain extent. Considering the absolute neutral air density observations at the middle atmosphere are rare. There is no alternative to the TIMED/SABER data that can cover the globe and have continuous observations over a long period of time. In addition, according to the results obtained in this paper, the density of NRLMSISE-00 can be effectively corrected to be closer to that of SABER by using the correction method in this paper. Therefore, the correction method in this paper is feasible. After obtaining other high-precision detection data, the method in this paper can be used to further improve the accuracy of NRLMSISE-00.

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