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The upper atmospheric effects of the 10 September 2017 solar flare at Mars

Xiaohua Fang (1), David Pawlowski (2), Yingjuan Ma (3), Edward Thiemann (1), Chuanfei Dong (4), Stephen Bougher (5), Francis Eparvier (1), Christina O. Lee (6), Yaxue Dong (1), Phillip Chamberlin (1), Mehdi Benna (7), Meredith Elrod (7), Wenbin Wang (8), Paul Mahaffy (7), and Bruce Jakosky (1)
(1) Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, USA, (2) Eastern Michigan University, USA, (3) University of California, Los Angeles, USA, (4) Princeton University, USA, (5) University of Michigan, Ann Arbor, USA, (6) University of California, Berkeley, USA, (7) NASA Goddard Space Flight Center, USA, (8) High Altitude Observatory, National Center for Atmospheric Research, USA
(xiaohua.fang@lasp.colorado.edu)

Abstract

Solar flares produce a burst of radiation over a wide range of wavelengths including X-ray and extreme ultraviolet (EUV), which are the main ionizing solar irradiance for planetary atmospheres at low and high altitudes, respectively. However, unlike Earth, the details of how the near-Mars space environment responds to this type of episodic transient events are poorly understood. In this study, we perform the first global, time-dependent numerical simulation of the Mars upper atmospheric and ionospheric responses to an X8.2-class solar flare event on 10 September 2017. The Mars Global Ionosphere-Thermosphere Model is applied using realistically configured solar irradiance conditions for the flare event. Our calculation results show that the ionospheric and atmospheric responses to the solar flare are distinctly different, not only on response regions in altitude but also on response time scales.

1. Introduction

Solar flares produce a burst of radiation on time scales of minutes to hours, releasing a tremendous amount of energy. It is important to understand the resulting space weather effects, not only from a scientific perspective, but also due to operational needs. The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission is the first Mars orbiter that carries a dedicated solar irradiance monitor, Extreme Ultraviolet Monitor (EUVM), together with a suite of particle and field measurement instruments. This provides an unprecedented opportunity for us to uncover the cause-effect chain between solar flare radiation bursts and Martian ionospheric and atmospheric perturbations. A global numerical simulation and its comparison with MAVEN observations are invaluable in not only interpreting satellite measurements but also providing a physics-based global context beyond along-track observations, which are subject to considerable limitation on spatial and temporal coverage of the spacecraft.

2. Numerical Simulation

The detailed solar irradiance spectra for this specific solar flare event are estimated using combined satellite measurements from MAVEN EUVM and SDO EVE [1]. The temporal variation of the solar radiation is then incorporated into the Mars Global Ionosphere-Thermosphere Model (MGITM) [2] to drive the upper atmosphere and ionosphere. By comparing the MGITM results under two controlled runs, one with the solar flare impact and the other under unperturbed conditions, we are able to retrieve and quantify the flare effects in the Martian upper atmosphere and ionosphere. Figure 1 presents direct model-data comparisons along pre-flare, in-flare, and post-flare orbits for this event, showing reasonably good agreement. More importantly, the model satisfactorily captures the neutral density enhancement during the flare and the subsequent recovery, on both spatial and temporal scales.

3. Results

Our numerical simulation illustrates that the ionospheric electron density reacts instantaneously to the flare photoionization enhancement, with a maximum increase by an order of magnitude in consistence with the flare time evolution. Neutral

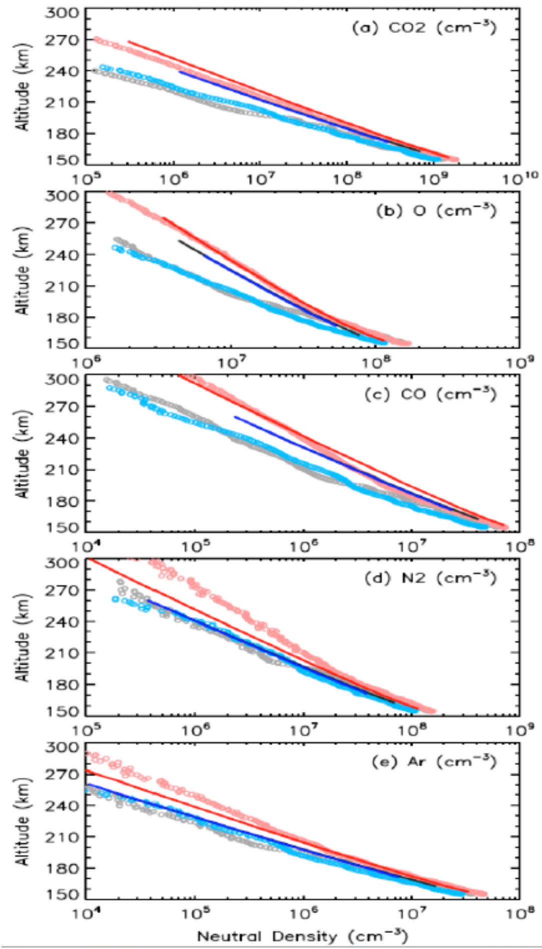

Figure 1. Comparison of the MGITM calculated CO_2, O, CO, N_2, and Ar densities with MAVEN NGIMS measurements along pre-flare (black), in-flare (red), and post-flare (blue) orbits for the 10 September 2017 solar flare event. The 3 periapsis passages are separated by approximately 9 hours. The model results and data are shown as solid lines and symbols.

particles, on the other hand, also respond to the heating effect of the solar flare, but significantly slower. It takes about 2.5 hours to reach the maximum disturbance and more than 10 hours to generally recover to the pre-flare state.

References

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