Supporting Information for
"Mars upper atmospheric responses to the 10 September 2017 solar flare: A global, time-dependent simulation"

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Supporting Figure S1

Additional Supporting Information

This supplement provides supporting information for the calculation of time-varying solar irradiance during the 10 September 2017 solar flare event.

Because of an especially high solar corona temperature associated with the flare, we adopt a physics-based spectral irradiance model for the wavelength range of 0.1-36 nm except for 30.5 nm, which uses flare plasma temperature measurements made from Earth and soft X-ray irradiance measurements made by MAVEN/EUVM. The EUVM 121.6 nm channel is used to estimate the 30.5 nm irradiance, and direct flare spectral measurement made from Earth by SDO EVE are used from 36-106 nm. The routine estimates of FISM-M [*Chamberlin et al.*, 2007, 2008; *Thiemann et al.*, 2017] are used above 106 nm. A de-

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tailed description of this composite irradiance spectrum has been given by *Thiemann et al.* [2018], and therefore is not repeated here.

Figure 1 shows the calculated solar irradiance spectra (in 1-nm wavelength resolution) and their evolution with time during the flare event. The transient nature of flares is well demonstrated in Figure 1a: the photon fluxes had an abrupt rise within ~15 min before reaching the peaks and then gradually recovered and largely dropped back to the pre-flare level about 4 hours later. For the comparison purpose, we select three time points on September 10 15:00 UT, 16:15 UT, and 17:42 UT as representatives of pre-flare, peak-flare, and post-flare conditions, respectively. It is well known that solar flares have different time scales in onset and decay characteristics at different wavelengths [e.g., *Fletcher et al.*, 2011, and references therein], which is also seen in Figure 1a in the X-ray and EUV irradiance changes with time. The choice of the flare peak at 16:15 UT is thus somewhat arbitrary, which, nevertheless, is adequate to help characterize the time scales in association with atmospheric perturbations. Our model results, as presented in this paper, illustrate that the time scale in the responses of the neutral regime of the upper atmosphere is much longer than that in the flare spectral variability. In addition, the post-flare time of 17:42 UT is selected, because it is the time when MAVEN reached periapsis of ~155 km altitude. Note that the orbital period of the spacecraft is about 4.5 hours, which means MAVEN missed the chance to closely observe the upper atmospheric responses during the peak of the flare event. This, on the other hand, underscores the importance and irreplaceability of global modeling in a time-evolving manner, like in the present study. The brief bite outs within 1-10 nm wavelengths at a time cadence of the MAVEN orbital period are not real but caused by the instrument effects of EUVM, which either pointed away from the Sun or happened to not open its aperture. These radiation bite outs have an insignificant effect because of being well outside of the flare event.

Figures 1b and 1c show that the flare spectral intensity has the most pronounced variability at short wavelengths, particularly <20 nm. The short-wavelength end of the spectrum undergoes rapid changes in both rising and decay phases. The time sequence in Figure 1a shows that at 16:15 UT, the total solar fluxes integrated over 0-10 nm, 10-20 nm, and 20-100 nm are enhanced by a factor of 8.68, 2.90, 1.23, respectively, in comparison with the pre-flare level at 15:00 UT. The respective irradiance enhancement factors significantly dropped to 2.92, 1.39, 1.13 at 17:42 UT, and further to 1.63, 1.08, 1.06 at 20:00 UT. This indicates two main characteristics of the solar flare development: short duration (~4 hours for this case) and wavelength-dependent variability (greater changes at the shorter wavelengths).

References

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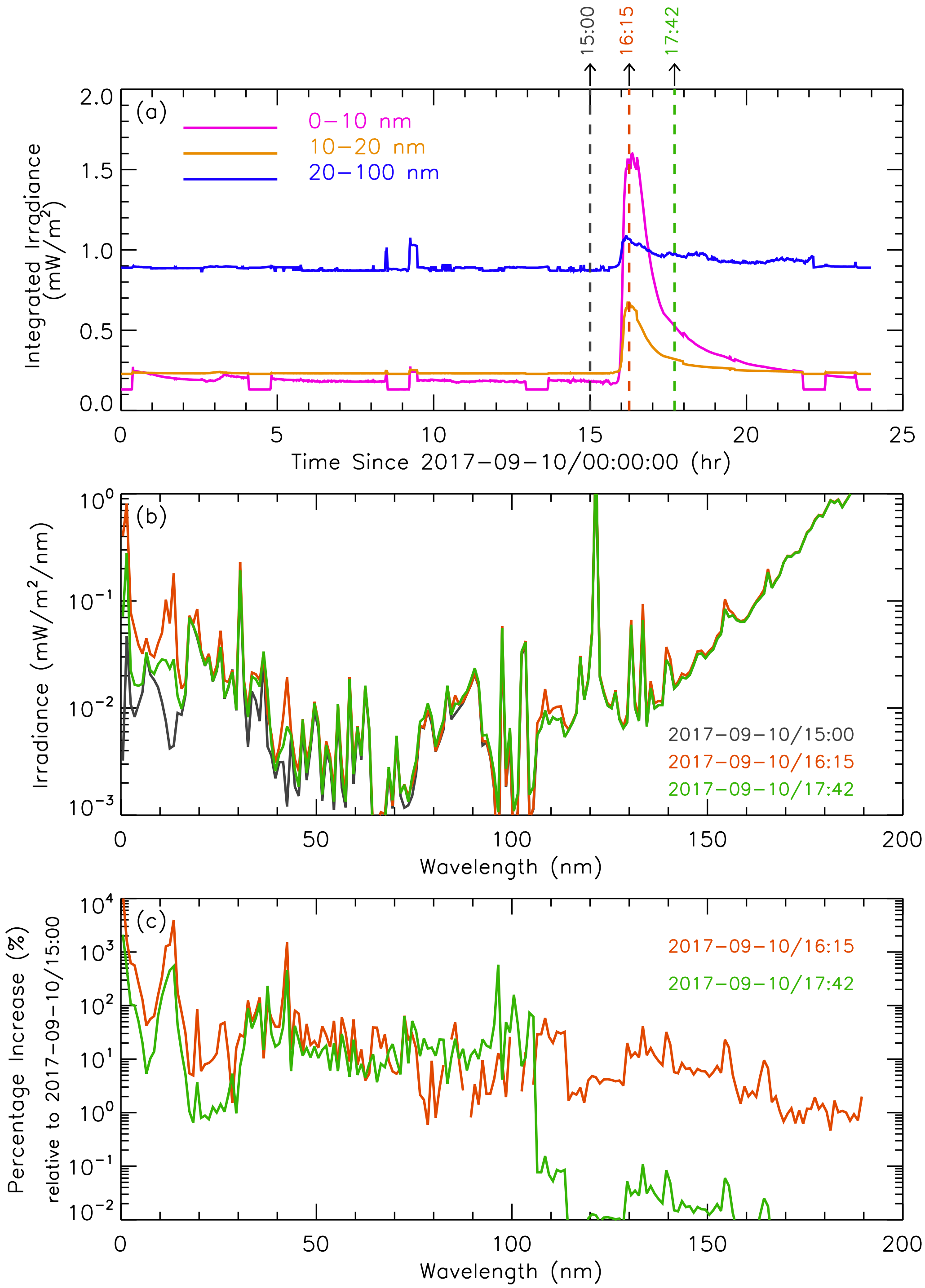

Figure 1. The calculated solar irradiance and variation with time during the 10 September 2017 solar flare event. Panel (a) shows the irradiance integrated within various wavelength ranges and the time evolution during the event. Panel (b) compares the detailed spectra at three time points as marked in the top panel, which are representative of pre-flare (black), peak-flare (red), and post-flare (green) conditions, respectively. Panel (c) shows the percentage increases of the spectral intensity at the peak- and post-flare phases relative to the pre-flare condition.