

# 1 **Wavelength dependence of solar flare irradiation and its** 2 **influence on the thermosphere**

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**Abstract.**

The wavelength dependence of solar flare enhancement is one of the important factors determining how the Thermosphere-Ionosphere (T-I) system response to flares. To investigate the wavelength dependence of solar flare, the Flare Irradiance Spectral Model (FISM) has been run for 34 X-class flares. The results show that the percentage increases of solar irradiance at flare peak comparing to pre-flare condition have a clear wavelength dependence. In the wavelength range between 0 - 195 nm, it can vary from 1% to 10000%. The solar irradiance enhancement is largest ( 1000%) in the XUV range (0 - 25 nm), and is about 100% in EUV range (25 - 120 nm). The influence of different wavebands on the T-I system during the October 28th, 2003 flare (X17.2-class) has also been examined using the latest version of National Center for Atmospheric Research (NCAR) Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM). While

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17 the globally integrated solar energy deposition is largest in the 0 - 14 nm  
18 waveband, the impact of solar irradiance enhancement on the thermosphere  
19 at 400 km is largest for 25 - 105 nm waveband. The effect of 122 - 195 nm  
20 is small in magnitude, but it decays slowly.

## 1. Introduction

21 Solar flare is a sudden, intense release of magnetic energy in the atmosphere of the Sun,  
22 which produces rapid increase in electromagnetic radiation from gamma rays to radio wave-  
23 lengths. One can classify a flare as a C, M, or X flare according to the maximum flux of soft  
24 X-ray flux in the 0.1 - 0.8 nm range of the spectrum measured near the Earth [*Garcia, 2000*].  
25 While C-class flares are a common occurrence during years near solar maximum, the frequency  
26 of X-class flares is always low. The solar UV photons are a heating source to the neutral and  
27 ionized constituents of the thermosphere-ionosphere (T-I) system. The extra ionization in the  
28 ionosphere caused by flares increases electron density, which influences the absorption and re-  
29 fraction of radio waves propagating through the ionosphere from one station to another. Also,  
30 flares are often associated with coronal mass ejection (CME), which may cause significant ge-  
31 omagnetic storms [*Tandberg-Hanssen and Emslie, 1988*].

32 Previously, studies of the thermospheric and ionospheric responses to solar flares have been  
33 conducted [*Tsurutani et al., 2005; Sutton et al., 2006; Zhang et al., 2011*]. The impacts of  
34 flares to T-I system varies because flares may have different magnitudes, locations on the solar  
35 disk, rise rates and decay rates. The enhancement of the extreme ultraviolet (EUV) spectral  
36 irradiance depends on the location of a flare, while flare enhancement of soft X-ray (XUV)  
37 depends weakly on the location [*Qian et al., 2010*]. There is also a large spectral difference  
38 between flares in magnitude [*Thomson et al., 2004*]. We expect that the impact of solar flare  
39 to the upper atmosphere depends on the spectral components with different wavelength, which  
40 not only have different irradiance, but also ionize different parts of the upper atmosphere. The

41 XUV dominates ionization in the lower thermosphere ( $< 150km$ ), while EUV dominates in the  
42 upper thermosphere [Qian *et al.*, 2011].

43 The purpose of this paper is to investigate how different wavebands of solar flare im-  
44 pact thermosphere and ionosphere. We use the National Center for Atmospheric Research  
45 (NCAR) Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)  
46 [Roble and Ridley, 1994] to simulate the thermospheric and ionospheric responses to idealized  
47 flares. Flare spectra estimated by the Flare Irradiance Spectral Model (FISM) [Chamberline  
48 *et al.*, 2007, 2008] are used as solar input to TIE-GCM. The solar flare spectrum is divided  
49 into 6 different wavebands: 0 - 14 nm, 14 - 25 nm, 25 - 105 nm, 105 - 120 nm, 121.56 nm  
50 (*Lyman -  $\alpha$* ) and 122 - 195 nm. Due to large variations during flares for different wavelengths  
51 and lack of measurements from SEE, the uncertainty of FISM flare component has wavelength  
52 dependence and varies from 10% to above 100%. However, compared to models with only daily  
53 components, FISM improves the estimation of solar flares significantly.

## 2. Model Description

### 2.1. FISM Solar Flare Model

54 Flare Irradiance Spectral Model (FISM) is an empirical model of the solar irradiance spec-  
55 trum from 0.1 to 195 nm at 1nm resolution and on 1-minute time cadence. The high temporal  
56 resolution of FISM makes it possible to study the variations due to solar flares. This model is  
57 based on the data provided by the Solar Extreme ultraviolet Experiment (SEE) on the Thermo-  
58 sphere Ionosphere Mesosphere Energetic and Dynamics (TIMED) satellite and the Solar Stellar  
59 Irradiance Comparison Experiment (SOLSTICE) on the Upper Atmosphere Research Satellite  
60 (UARS). The flare component of FISM including both the impulsive and gradual phase varia-

61 tions is based on a reference set of 39 large flares from 2002 to 2005 measured by the TIMED  
62 SEE [*Chamberline et al.*, 2008].

## 2.2. NCAR TIE-GCM

63 The latest version (v1.94) of the National Center for Atmospheric Research (NCAR) TIE-  
64 GCM is employed. TIE-GCM is a first-principle, three-dimensional, non-linear representation  
65 of the coupled thermosphere and ionosphere system. It solves the momentum, energy and  
66 continuity equations for neutral and ion species in pressure coordinates [*Roble et al.*, 1988], with  
67 a self-consistent calculation of ionospheric wind dynamo effects [*Richmond et al.*, 1992]. The  
68 external forcing of TIE-GCM are mainly the solar irradiance, magnetospheric energy, and tidal  
69 perturbations at the lower boundary of the model. Magnetospheric energy inputs include auroral  
70 particle precipitation and high-latitude ion convection. The Heelis potential model [*Heelis et al.*,  
71 1982] is used to specify the high-latitude electric field in this study. The TIE-GCM is run with  
72  $5^\circ \times 5^\circ \times$  half scale height resolution (longitude  $\times$  latitude  $\times$  altitude).

73 Another NCAR upper atmospheric model, Thermosphere-Ionosphere-Mesosphere-  
74 Electrodynamic General Circulation Model (TIME-GCM) [*Roble and Ridley*, 1994] covers  
75 the altitudinal range from 30 km to 600 km, including mesosphere. Compared to TIE-GCM,  
76 TIME-GCM includes absorption in UV wavelengths such as  $O_2$  absorption in Shumann-Runge  
77 continuum and Shumann-Runge bands, and  $O_3$  dissociation from the Herzberg, Hartley,  
78 Huggins, and Chappius bands [*Qian et al.*, 2011]. However, TIE-GCM and TIME-GCM use  
79 the same solar energy deposition scheme for the XUV and EUV, and also photoionization is  
80 calculated for the altitude above 97 km for both TIE-GCM and TIME-GCM. Therefore, both  
81 could be used for flare study.

### 3. Results

#### 3.1. FISM data for X-class flares

82 Figure 1 depicts the FISM outputs for a X17.2 flare on October 28th, 2003 (day of year  
83 301). The top panel shows the time variation of total solar flux integrated for 0 - 195 nm  
84 wavelength, which started to increase at 11:00 UT and reached maximum flux  $100 \text{ mW}/\text{m}^2$  at  
85 around 11:07 UT. The wavelength dependences of solar flux before flare and at flare peak are  
86 shown in the middle panel. The pre-flare dependence is in black which is also denoted by the  
87 triangle in the top panel, while the red line is for the time at flare peak which is denoted by  
88 diamond in the top panel. The flux enhancement varies for different wavelengths, which is also  
89 illustrated in the bottom panel, the percentage increase of solar flux comparing the flare peak to  
90 the pre-flare condition has wavelength dependence. In the wavelength range between 0 - 195  
91 nm, the percentage increase can vary from several percents up to 10000%. The solar irradiance  
92 increased largest in the XUV range, about 1000% on average, and increased about 100% in  
93 EUV range on average.

94 To have a better understanding of the wavelength dependence of percentage increase of X-  
95 class flares, we examine the spectra of 34 X-class flares observed between year 1989 and 2012  
96 using FISM. As depicted in Figure 2, the percentage increase can vary from 0.1% up to 10000%  
97 depending on the wavelength in 0 - 195 nm range. There is not very large enhancement in 15 - 25  
98 nm wavelength range, which contains many strong solar emission lines, such as the Fe IX. When  
99 a flare happens these emissions don't increase very much, and sometimes even decrease. This is  
100 because most of these emissions are formed in the solar corona at the approximate temperatures  
101 of the corona around 1 to 2 million degrees (Kelvin). When there is a significant heating that  
102 heats the source ions to much higher temperatures, Fe IX quickly becomes Fe XX, for example.

103 Therefore, the source ion population is depleted [*Woods et al.*, 2011]. The low enhancement in  
104 115 - 129 nm range is rather instrumental. In the TIMED/SEE instrument, which FISM is based  
105 on, an Aluminum filter had to be put in place to block 99% of the *Lyman* –  $\alpha$  emission line  
106 at 121.56 nm so that it will not saturate the detector [*Eparvier et al.*, 2001]. However, it does  
107 not allow the 'wings' on each side to be measured significantly. Therefore, they all behave very  
108 close to the *Lyman* –  $\alpha$  emission in the model. It was also found that there is an approximately  
109 linear relation between solar irradiance in wavelength 0.1 - 0.8 nm and irradiance in 0 - 14 nm,  
110 which are all coronal emission [*Chamberline et al.*, 2008].

111 The solar spectra from FISM is used as the solar input for TIE-GCM. Since the purpose  
112 of our study in this paper is to investigate the thermospheric response to flares in different  
113 wavelengths, the penetration depths of solar irradiance with different wavelengths through the  
114 atmosphere should also be a criteria to divide the spectra into different wavebands. The local  
115 absorption rate depends on the product of absorption cross-section and the total abundance of  
116 the absorbing species along the path, which is known as the optical depth. The maximum  
117 absorption occurs at the altitude where the optical depth is unit. According to the wavelength  
118 dependence of altitude for unit optical depth shown in Figure 1 in *DeLand and Cebula* [2012]  
119 (adapted from [*Meier*, 1991]), we divide the whole irradiance spectra from 0 - 195 nm into 6  
120 different wavebands: 0 - 14 nm, 14 - 25 nm, 25 - 105 nm, 105 - 120 nm, 121.56 nm, 122 - 195  
121 nm.

### 3.2. Response of high-altitude thermosphere to flare at different wavelengths

122 As discussed above, in order to investigate the influence of solar flare at different wavelengths,  
123 we divide the irradiance spectra of FISM (0 - 195 nm) into six different wavebands: 0-14 nm  
124 and 14-25 nm wavebands for XUV irradiance, 25-105 nm and 105-120 nm for EUV irradiance,



125 Lyman-alpha line (121.56 nm) and 122-195 nm waveband for far ultraviolet (FUV) irradiance.  
126 On October 28th, 2003 (Day of year, 301), there was a X17.2-class solar flare, which was  
127 one of the most severe flares in the last solar cycle. For each waveband, for example, 0 - 14 nm  
128 wavelengths, we run 2 cases using TIE-GCM. For case 1, we run TIE-GCM using constant solar  
129 input at pre-flare condition for DOY 301, and for case 2, using time varying solar input only  
130 within 0 - 14 nm wavelength. The difference between these two runs represents the influence  
131 of solar irradiance within 0 - 14 nm waveband to the thermosphere. The influences of solar  
132 irradiance within other wavebands are also calculated in this way. To minimize geomagnetic  
133 influences, all the simulations are under the geomagnetic quiet condition ( $Kp = 1$ ). In this  
134 study, the results are analyzed in terms of values integrated or averaged over the globe.

135 Figure 3 shows the temporal variations of solar irradiance flux in 0 - 14 nm, 25 - 105 nm  
136 and 122 - 195 nm wavebands and their influences on the thermosphere. We only show the  
137 wavebands of FISM spectrum which have non-negligible thermospheric effect. The solar flux  
138 variations for different wavebands calculated from FISM are depicted in the first panel, which  
139 illustrates that the solar flux in 0 - 14 nm waveband was quite small before flare compared to  
140 that in 122 - 195 nm waveband, but it increased most by about  $20 \text{ mW}/\text{m}^2$ . The second panel  
141 shows the enhancements of globally integrated solar energy deposition in the upper atmosphere  
142 during the flare. The peak of solar energy deposition for 0 - 14 nm is the largest and almost  
143 three times larger than the peak for 25 - 105 nm, which is also shown in table 1. However,  
144 the time integration of global solar energy (TIGSE) for 25 - 105 nm waveband is only half of  
145 the TIGSE for 0 - 14 nm and even larger than the one for 122 - 195 nm waveband. The third  
146 panel depicts the Joule heating enhancement that shows quite different responses in time and  
147 magnitude for different wavebands. There is a rather rapid and large enhancement of Joule

148 heating responding to the solar flare irradiance for 0 - 14 nm waveband, however, for 122 - 195  
149 nm, the peak of Joule heating enhancement is negligible and has a obvious delay to the flare  
150 peak. The response for 25 - 105 nm is somewhat combination of the ones for 0 - 14 nm and 122  
151 - 195 nm wavebands. The total timely integration of global solar energy increased by  $6.79 \times 10^{10}$   
152 J for the solar flare on October 28th, 2003, while the timely integration of global joule heating  
153 increased comparably little by  $1.86 \times 10^9$  J. The fourth and bottom panels depict the thermospheric  
154 temperature and density perturbations at 400 km. The altitude 400 km was chosen because this  
155 is the altitude range where low-Earth satellites fly. As also illustrated in table 1, although the  
156 largest energy deposition comes from solar irradiance in 0 - 14 nm wavelength, most of the  
157 thermospheric perturbations at 400 km are due to 25 - 105 nm waveband while the impact of  
158 122 - 195 nm is negligible. The high-altitude temperature and density perturbations divided by  
159 the solar energy deposition peak or the TIGSE is an order larger for 25 - 105 nm waveband  
160 than those for the other two wavebands. Therefore, the solar irradiance in 25 - 105 nm of  
161 EUV influences the high-altitude thermosphere most effectively. The high-altitude temperature  
162 and neutral density response 3 ~ 5 hours later than the flare peak, as a result of the different  
163 energy deposition heights and amounts for irradiance with different wavelengths. As discussed  
164 in *Huang et al.* [2012], the characteristic response timescale of the upper-thermosphere depends  
165 on the height of heat deposition, as shown in Figure 4. The temperature response at 400 km to  
166 the high-altitude heating is much stronger and faster than the response to low-altitude heating.

### 3.3. Response of T-I system to flare at different wavelengths at flare peak

167 Figure 4 depicts the altitudinal distributions of perturbations due to solar irradiance in differ-  
168 ent wavebands at the flare peak. Most of the solar energy is deposited below 150 km by the 0  
169 - 14 nm and 122 - 195 nm wavebands, while the energy deposition in 25 - 105 nm dominates

170 above  $\sim 160$  km. This results in the largest perturbations of electron density and Pedersen  
171 conductivity due to 0 - 14 nm waveband in E region and due to 25 - 105 nm in F region. En-  
172 hancement of the 122-195nm waveband impacts the thermosphere through dissociation, which  
173 results in little effect on the electron density and Pedersen conductivity variation. The tempera-  
174 ture perturbation below  $\sim 150$  km is also largest due to energy deposition in 0 - 14 nm and 122  
175 - 195 nm wavebands, while for the upper thermosphere it is largest due to deposition in 25 - 105  
176 nm. Therefore, the solar radiation in 25 - 105 nm is important for high altitude ionization and  
177 heating at flare peak.

### 3.4. Temporal variation of thermospheric enhancements due to solar irradiance at different wavelengths

178 The enhancements were calculated through taking the difference between the flare and non-  
179 flare runs for each waveband. Figure 5, 6, 7 and 8 show the temporal variations of the  
180 altitudinal distribution of solar energy deposition percentage increase, Pedersen conductivity  
181 percentage increase, temperature increase and neutral density percentage increase due to solar  
182 irradiance in different wavelengths. The line plots represent the temporal variations at 400 km  
183 altitude. As shown in Figure 5, the total solar energy deposited into the upper atmosphere  
184 increases up to 140% due to the solar irradiance enhancement within 0 - 195 nm, initially  
185 deposited under 150 km but lasts longer in the higher altitude. The Pedersen conductivity  
186 enhancement can reach up to 300% in low altitudes. The absorption rate at an arbitrary altitude  
187 is proportional to the multiplication of neutral density and photon flux. Changes in the upper  
188 atmosphere following a flare might not simply due to the thermal inertia of the atmosphere,  
189 but might partly due to the fact that the altered density structure of the atmosphere absorbs  
190 non-flare irradiance differently from before the flare. For example, it is possible that the GSE

191 enhancement at high altitudes after the flare is not due to the residual flare irradiance, but rather  
192 to the fact that the neutral density has increased, so that more non-flare irradiance is absorbed  
193 at a given altitude. The maximum of temperature enhancement is 45 K and the maximum of  
194 density enhancement is about 17%, which are both found in high altitudes and have 3 ~ 4 hour  
195 time delay to the flare peak. As discussed previously, the thermospheric response at 400 km to  
196 the high-altitude heating is much stronger and faster than the response to low-altitude heating  
197 [*Huang et al.*, 2012].

198 We divide the whole spectrum from 0 - 195 nm into different wavebands and investigate the  
199 impact of each waveband on the T-I system. As illustrated in the comparison of Figure 6,  
200 7 and 8, the temporal and altitudinal response of T-I system to solar flare irradiance varies  
201 significantly with irradiance wavebands. Although the maximum percentage increase of energy  
202 deposition is about 100%, the solar energy enhancement peaks at lower altitude below 150 km  
203 for 0 - 14nm, while the solar energy in 25 - 105 nm waveband deposited at higher altitude and  
204 increases up to 70%. The disturbances in T-I system, for example, globally averaged Pedersen  
205 conductivity, temperature and neutral density show that most of the high-altitude perturbations  
206 are due to 25 - 105 nm (part of EUV) waveband. Also, the energy deposition enhancement in  
207 122 - 195 nm waveband is below 150 km and impacts the thermosphere through dissociation,  
208 therefore, it has little effect on Pedersen conductivity, temperature and neutral density. However,  
209 the temperature and neutral density perturbations due to solar irradiance in this waveband do  
210 not decay as fast as those due to irradiance in 0 - 14 nm and 25 - 105 nm.

211 Figure 9 illustrates the nearly linear response of T-I system at 400 km to different wavebands  
212 of solar irradiance. The black lines represent the globally averaged perturbations of solar energy  
213 deposition, neutral density, temperature and electron density at 400 km due to the whole flare

214 spectrum from 0 to 195 nm, while the red lines represent the summations of perturbations at  
215 400 km due to 6 separated bands. The high-altitude response to the flare spectra in 0 - 195 nm  
216 is almost a linear combination of those to separated wavebands, which suggests a possibility to  
217 predict the variations of temperature, neutral and electron density at satellites orbits responding  
218 to the future flares according to the solar irradiance enhancement measured at different wave-  
219 bands.

#### 4. Conclusions

220 The response of T-I system to flare irradiance could be different in magnitude and duration  
221 due to the flares with different deposition heights, magnitudes of enhancement and durations  
222 for different wavebands. The wavelength dependence of solar flare enhancement is one of the  
223 important factors determining how the terrestrial atmosphere response to flares with different  
224 enhancement in wavelength. The FISM data show that for the 34 X-class solar flares between  
225 year 1989 and 2012, the solar irradiance comparing the flare peak to the pre-flare condition has  
226 wavelength dependence. In the wavelength range between 0 - 195 nm, the percentage increase  
227 can vary from 1% to 10000%. The solar irradiance increased largest in the XUV range (0 - 25  
228 nm), about 1000% on average, and the one in EUV range (25 - 120 nm) increased about 100%  
229 on average.

230 In this paper, we investigate how the thermosphere and ionosphere respond to the different  
231 wavebands of solar irradiance for the X17.2-class solar flare on October 28th, 2003. The solar  
232 irradiance spectra of FISM (0 - 195 nm) is divides into six different wavebands: 0-14 nm and  
233 14-25 nm wavebands for XUV range, 25-105 nm and 105-120 nm for EUV, *Lyman* -  $\alpha$  line  
234 (121.56 nm) and 122-195 nm waveband for FUV. For each waveband, for example, 0 - 14 nm  
235 wavelengths, we run 2 cases using TIE-GCM, one case 1 with constant solar input at pre-flare

236 condition, and the other case with time varying solar input only within 0 - 14 nm wavelength.  
237 The enhancements are calculated through taking the difference between the flare and pre-flare  
238 runs. The globally integrated solar energy deposition and the time integration of it was largest  
239 due to 0-14nm waveband compared to other wavebands. However, the time integration of Joule  
240 heating energy enhancement due to solar irradiance increases comparably for 0-14nm and 25-  
241 105nm wavebands. The impact of solar irradiance enhancement on the thermosphere at 400 km  
242 is largest for 25 - 105 nm waveband, which accounts for about 33 K in total 45 K temperature  
243 disturbance, and about 7.4% in total 11% neutral density disturbance. The effect of 122 - 195  
244 nm irradiance is little in magnitude, since it impacts the thermosphere through dissociation.  
245 Therefore, the solar irradiation at 25 - 105 nm impacts high-altitude heating and ionization  
246 most effectively.

247 For the future work, we plan to investigate more X-class solar flare events with different  
248 magnitudes and durations to get a better understanding and conclusion of their influences at  
249 different wavelengths.

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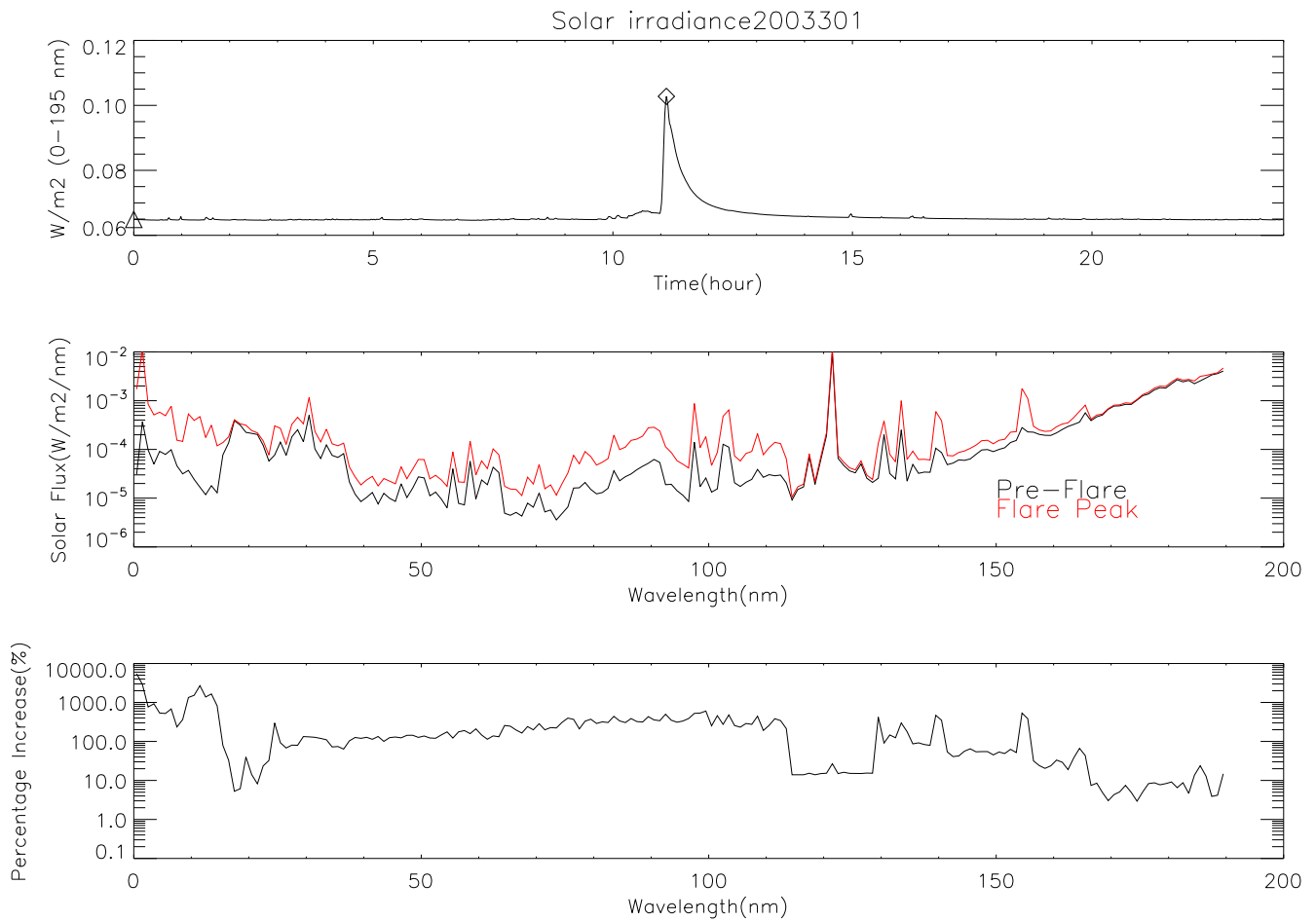


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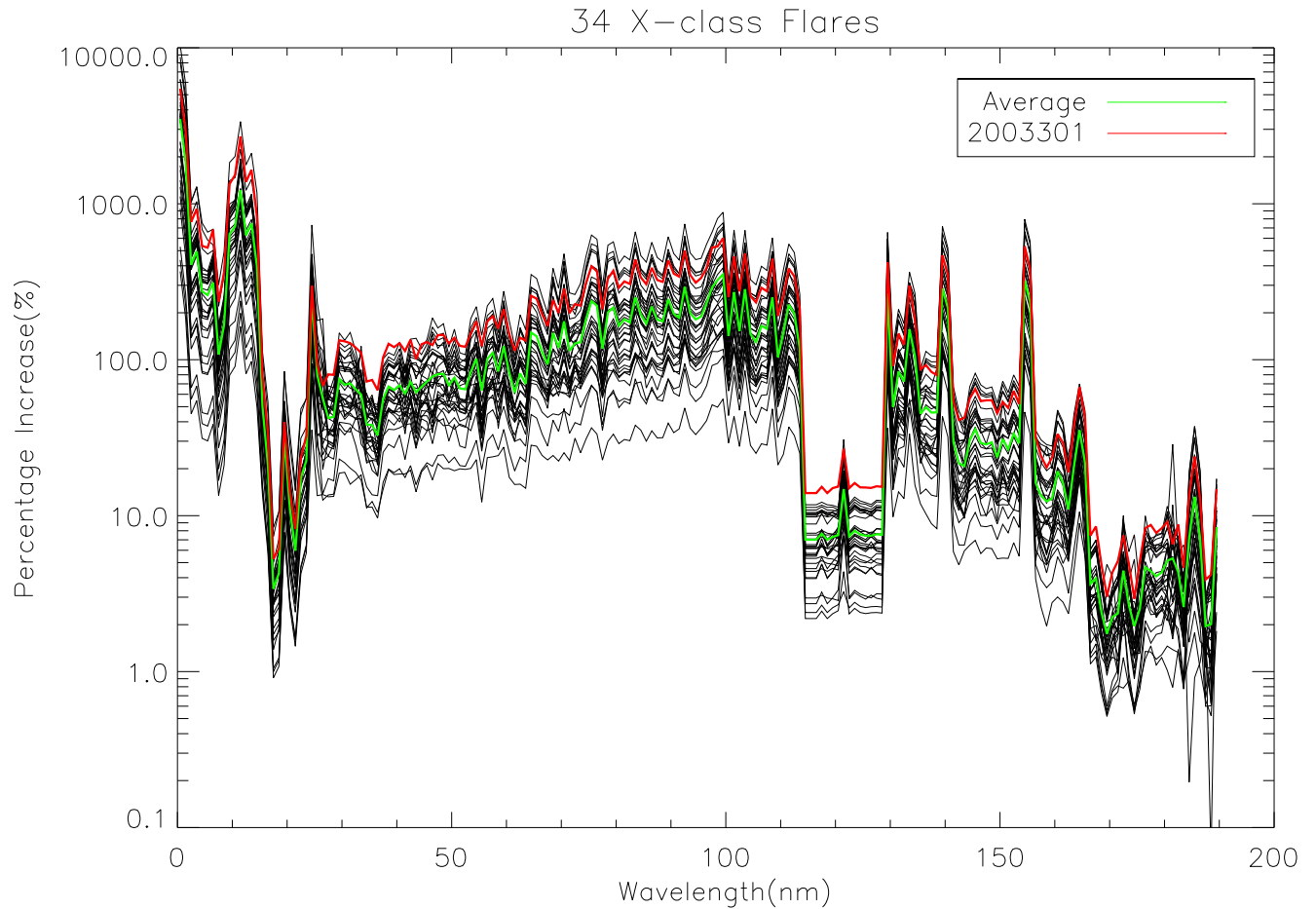
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**Table 1.** Heating efficiency of solar irradiance at different wavelengths to thermosphere at 400 km.

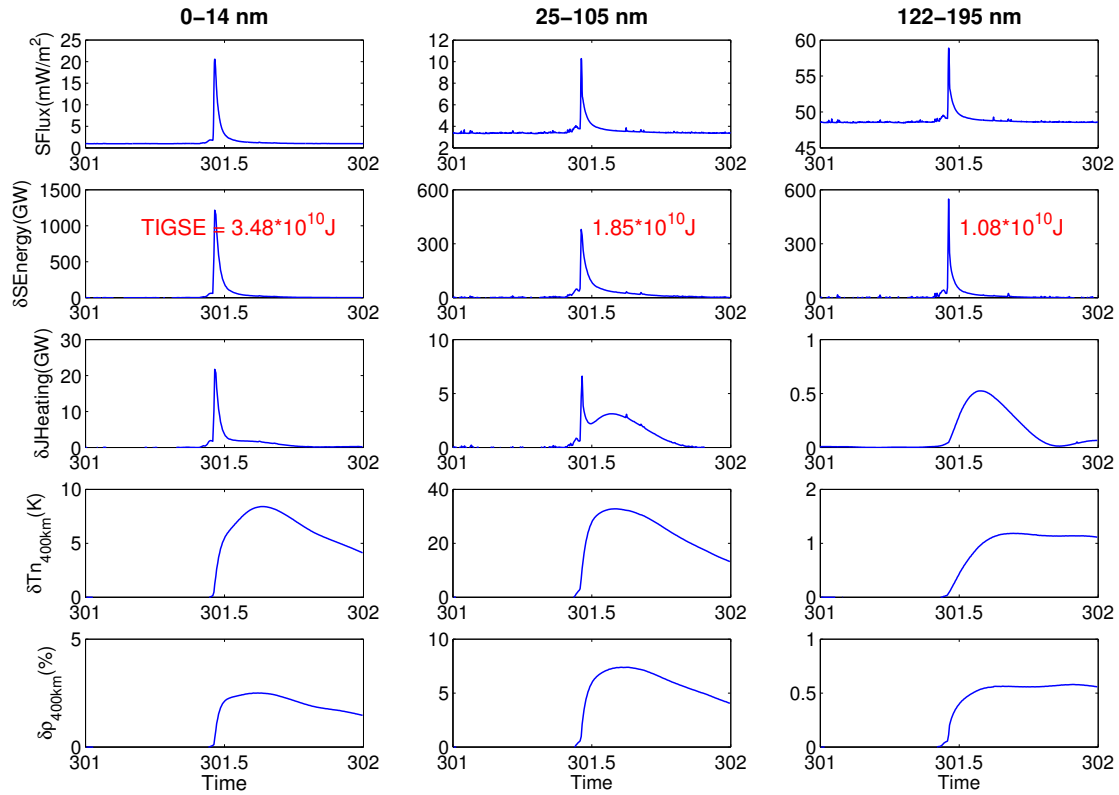
	0 – 14 nm	25 – 105 nm	122 – 195 nm
$\delta$ SE peak (GW)	1216	379	548
TIGSE (J)	3.48e10	1.85e10	1.08e10
$\delta$ Tn peak (K)	8.4	32.8	1.2
$\delta\rho$ peak	2.50%	7.39%	0.58%
$\delta$ Tn/ $\delta$ SE (K/GW)	0.0069	0.0865	0.0022
$\delta$ Tn/TIGSE (K/J)	2.41e-10	17.73e-10	1.09e-10
$\delta\rho$ / $\delta$ SE (%/GW)	0.0021	0.0200	0.0011
$\delta\rho$ /TIGSE (%/J)	0.7e-10	4.0e-10	0.5e-10



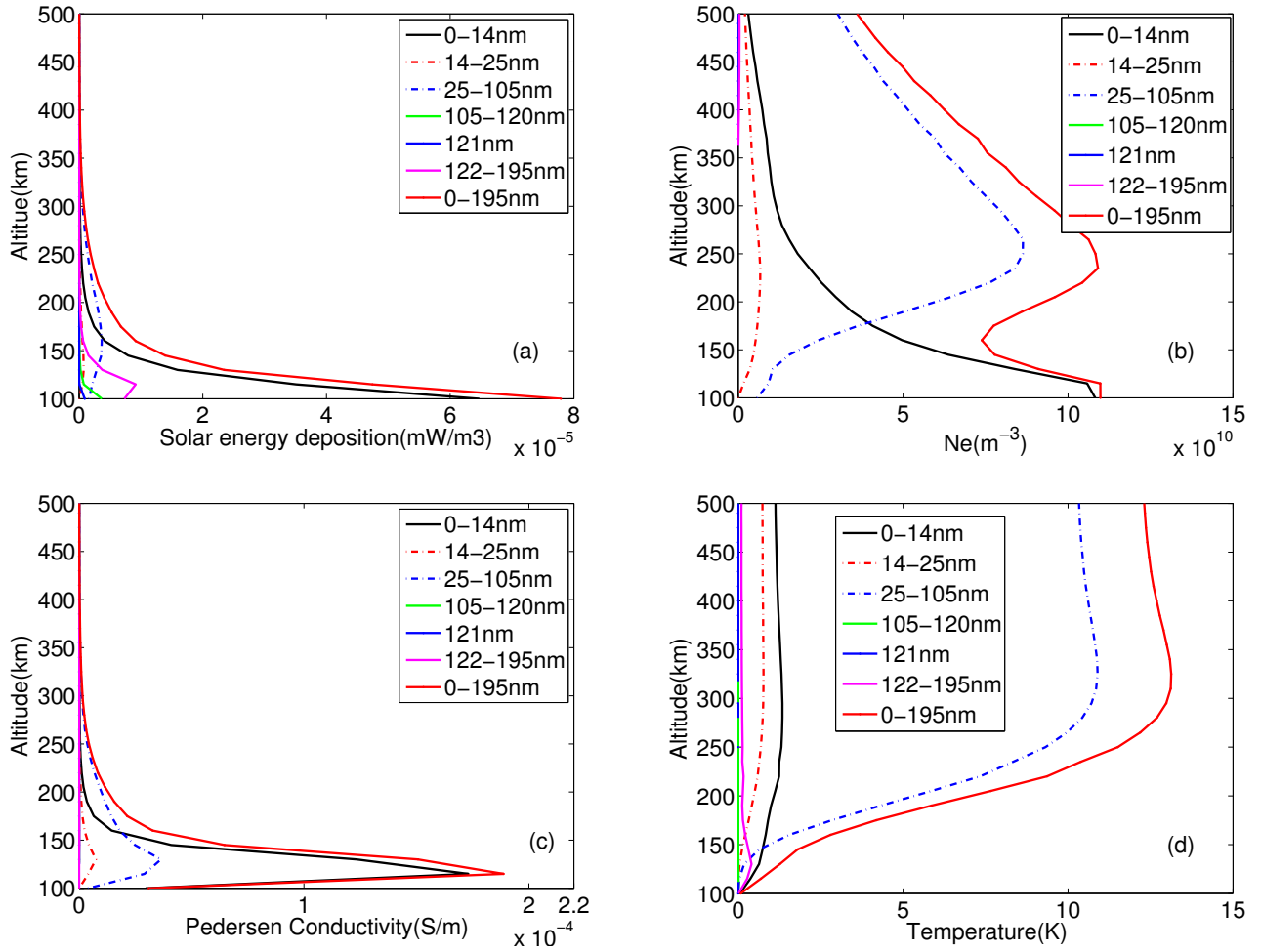
**Figure 1.** FISM solar irradiance results for X17.2 flare on October 28th, 2003 (day of year 301). Top: Time variation of total solar irradiance integrated over wavelength from 0 to 195 nm. The flare reached maximum flux  $0.1 W/m^2$  at around 11:07 UT. Middle: Solar spectra before flare at the moment denoted by triangle in top panel (black) and at flare peak denoted by diamond (red). Bottom: Percentage increase of solar irradiance comparing the peak and pre-flare conditions.



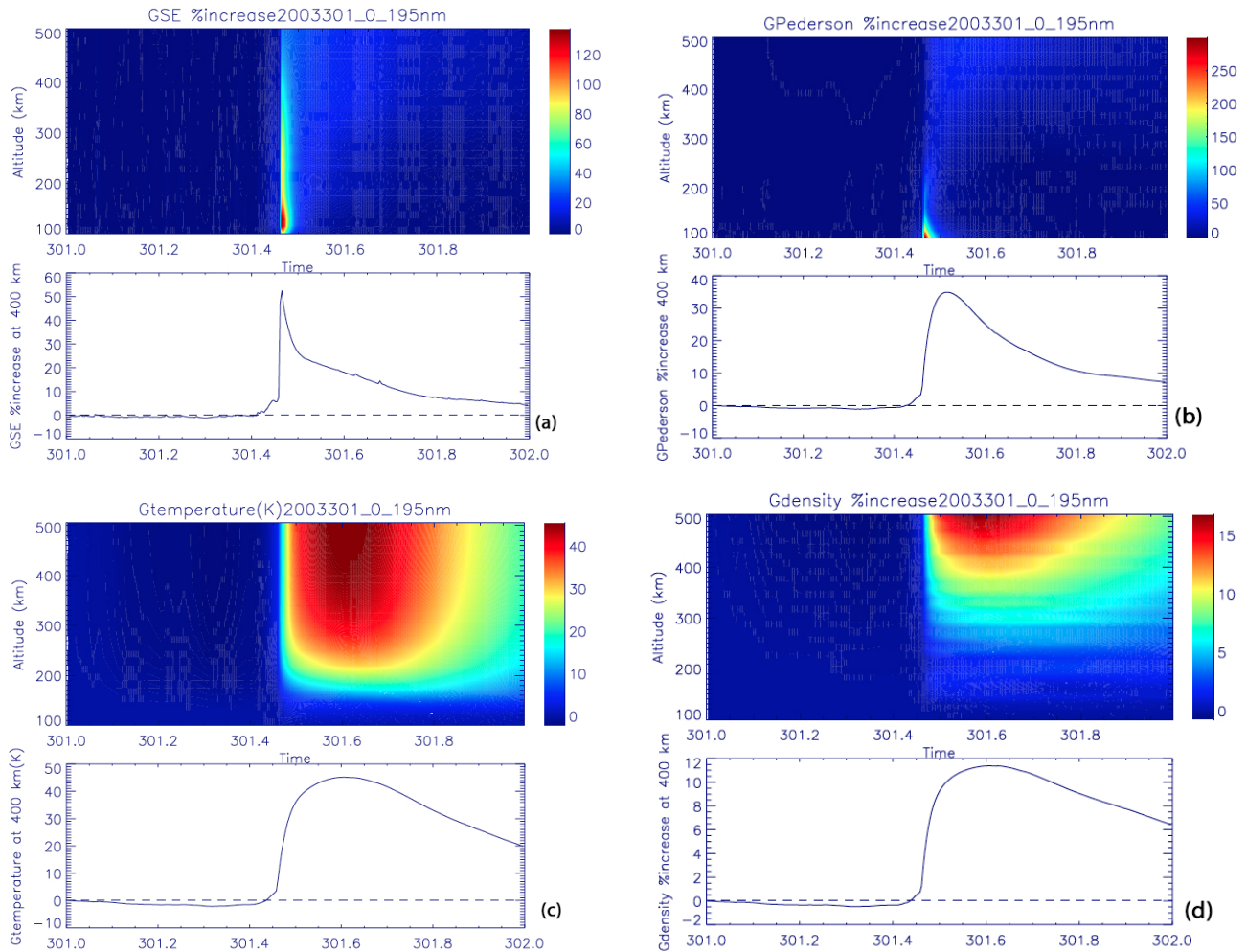
**Figure 2.** FISM solar irradiance results for percentage increases comparing the peak and pre-flare conditions for 34 X-class flares happened between year 1989 and 2012. The red line denotes the October 28th, 2003 flare event, and the green line is the average of 34 X-class flares. The low enhancement in 15 - 25 nm is a result of the depletion of source ion, while the low enhancement in 115 - 129 nm is rather instrumental.



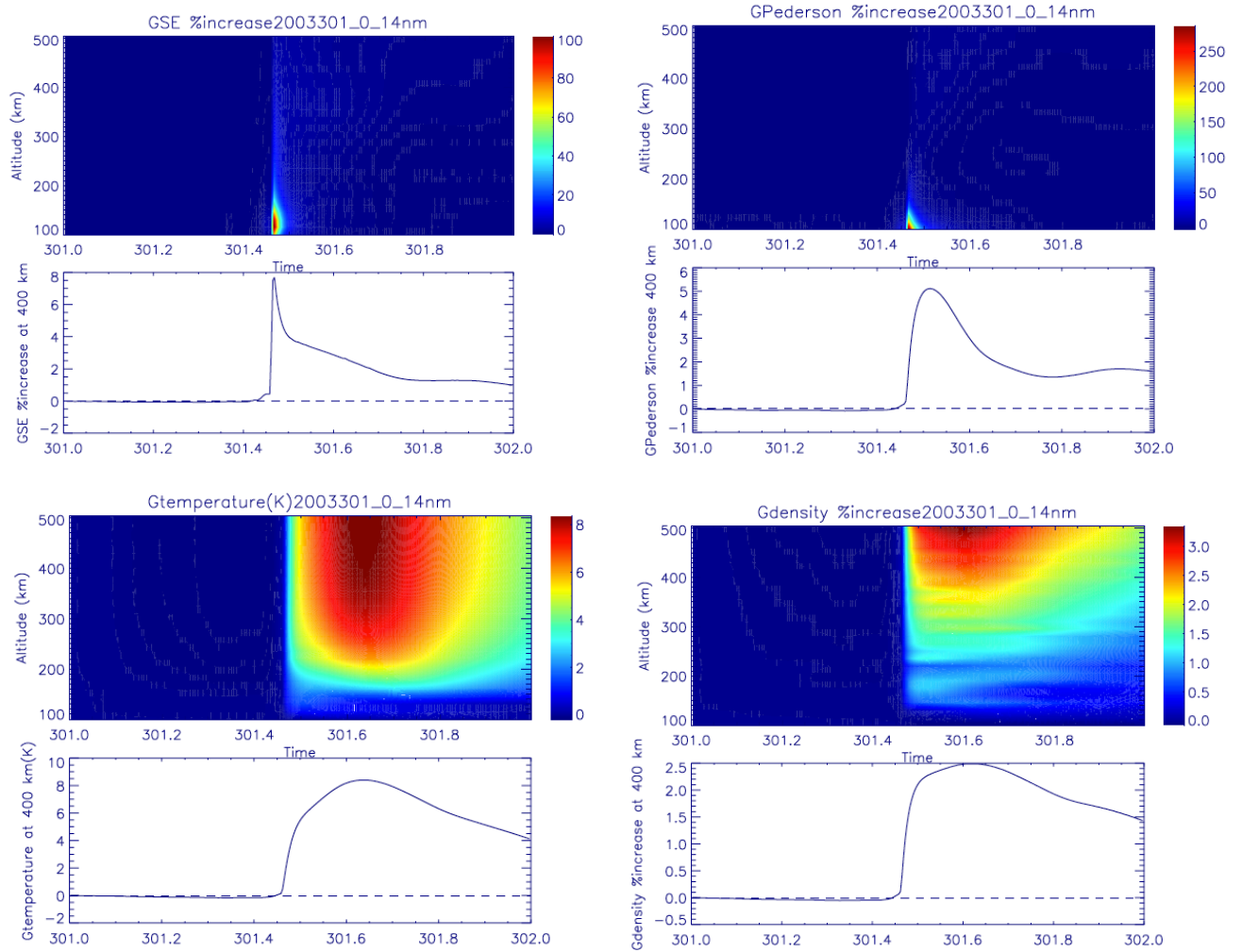
**Figure 3.** Time variations of different wavebands for DOY 301, first column for 0 - 14 nm, second column for 25 - 105 nm and third column for 122 - 195 nm. Top panel: Solar flux calculated from FISM. Second panel: Perturbation of global solar energy deposited into the upper atmosphere. The time integration of global solar energy (TIGSE) deposited are also labeled in red. Third panel: Perturbation of globally integrated Joule heating. Fourth panel: Globally averaged perturbation of temperature at 400 km. Bottom panel: Globally averaged perturbation of neutral density at 400 km.



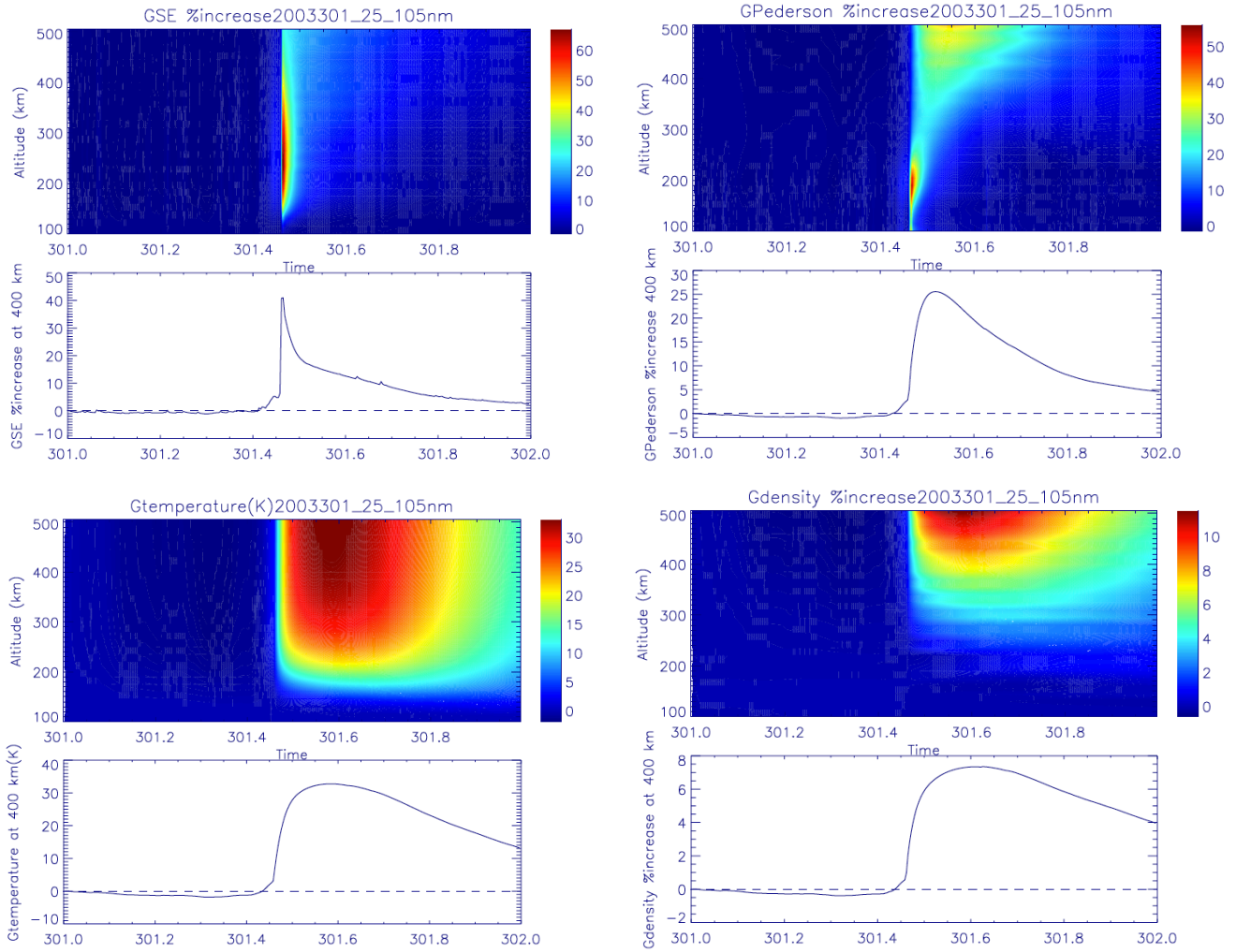
**Figure 4.** Altitudinal distribution of TIE-GCM simulation results at flare peak for solar irradiance in different wavelength ranges. (a) Globally averaged solar energy deposition. (b) Globally averaged electron density. (c) Globally averaged Pedersen conductivity. (d) Globally averaged temperature.



**Figure 5.** Temporal variations of the altitudinal distribution of TIE-GCM simulation results due to the solar irradiance enhancement in 0 - 195 nm wavelength range. (a) Globally averaged percentage increase of solar energy deposition. (b) Globally averaged percentage increase of Pedersen conductivity. (c) Globally averaged temperature enhancement. (d) Globally averaged percentage increase of neutral density. The line plots represent the temporal variations at 400 km altitude.

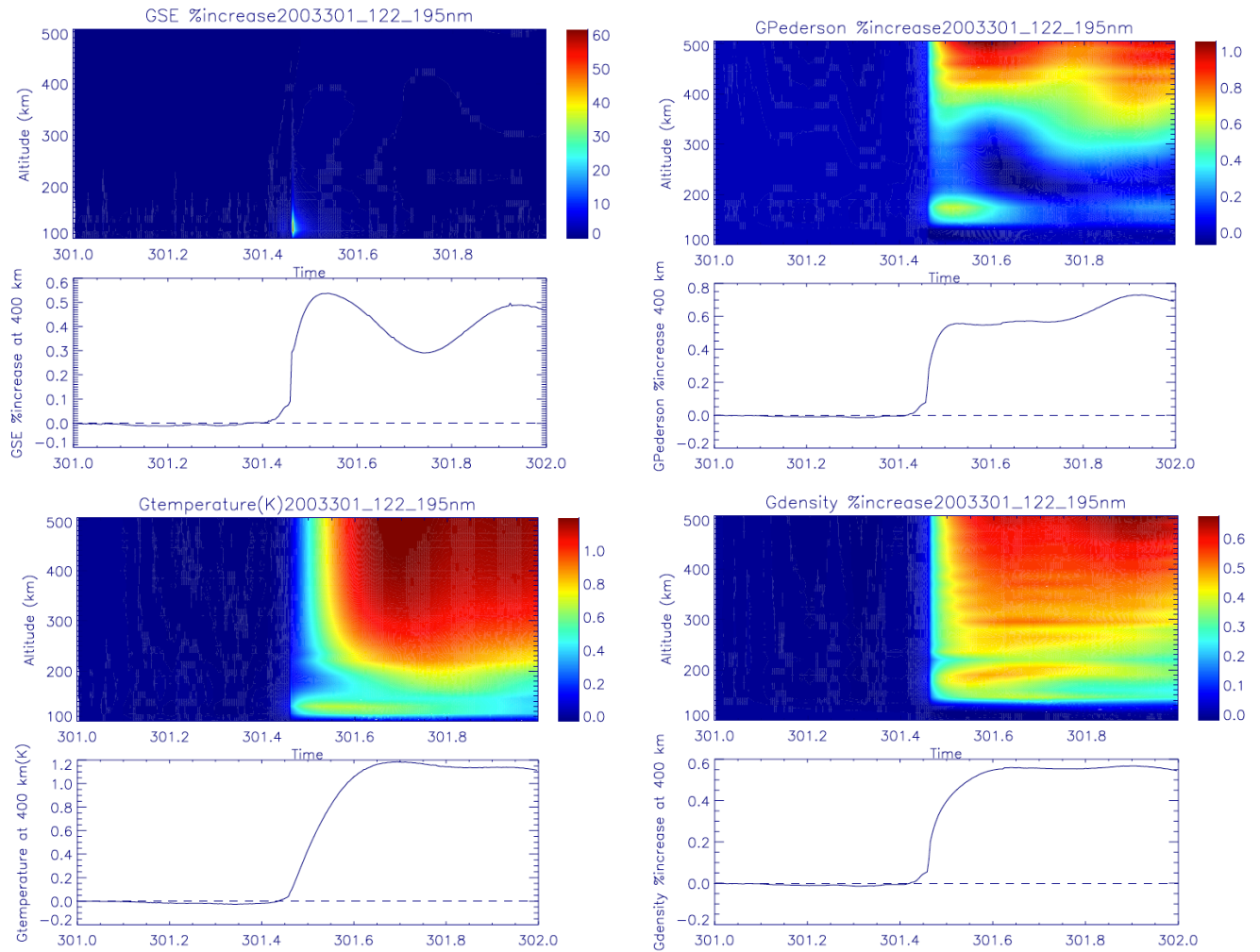


**Figure 6.** Same as Figure 5 but for the simulation results due to the solar irradiance enhancement in 0 - 14 nm wavelength range.

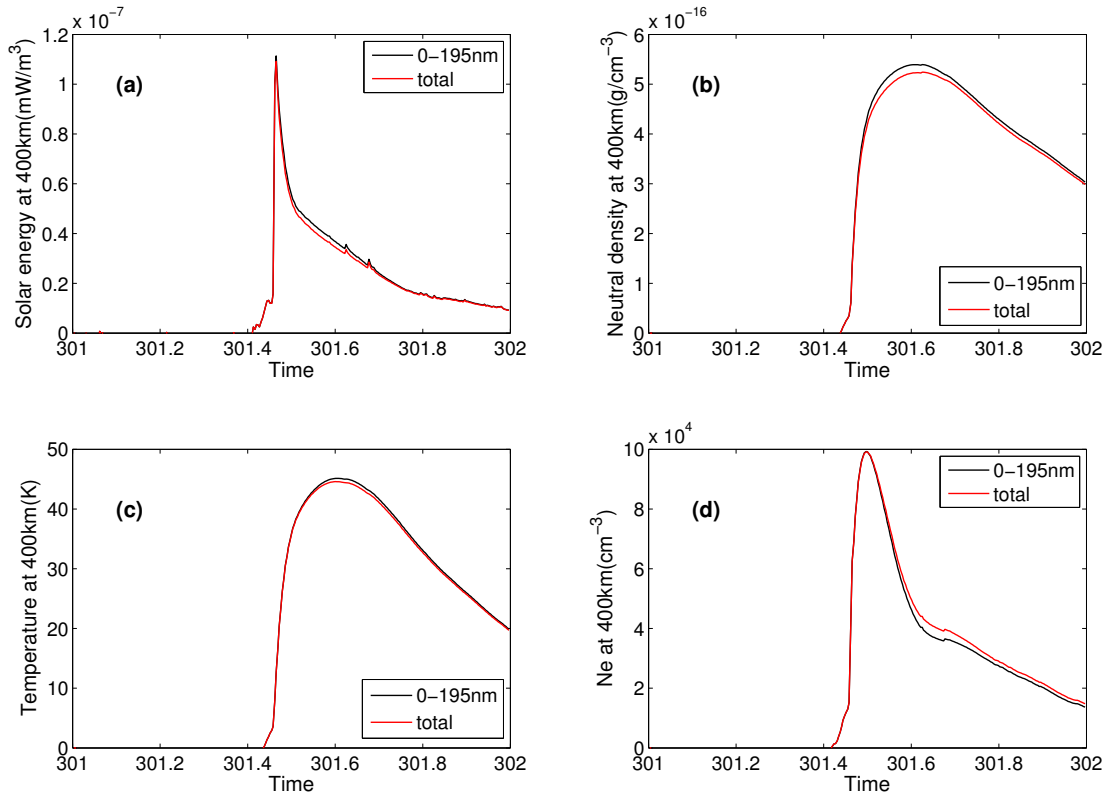


**Figure 7.** Same as Figure 5 but for the simulation results due to the solar irradiance enhancement in 25 - 105 nm wavelength range.





**Figure 8.** Same as Figure 5 but for the simulation results due to the solar irradiance enhancement in 122 - 195 nm wavelength range.



**Figure 9.** Comparison of TIE-GCM simulation results at 400 km. The black lines show the variations using FISM solar spectra in 0 - 195 nm as solar input, while the red lines represent the total sum of variations due to FISM spectra in separated wavebands. (a) Globally averaged solar energy deposited at 400 km. (b) Globally averaged neutral density at 400 km. (c) Globally averaged temperature at 400 km. (d) Globally averaged electron density at 400 km.