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Solar ultraviolet variability during the TIMED mission

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Abstract

The Thermosphere–Ionosphere–Mesosphere Energetics and Dynamics (TIMED) satellite was launched in December 2001 near solar cycle 23 maximum. The solar activity remained at a high level during 2002 and has since declined to moderate activity. As part of the TIMED mission objective to study the energetics of the upper atmosphere, the Solar EUV Experiment (SEE) aboard TIMED measures the solar extreme ultraviolet (EUV) energy input. The SEE instrument is measuring the solar UV irradiance with a spectral resolution of 0.4 nm between 27 and 194 nm and with 7–10 nm resolution shortward of 27 nm. The solar UV irradiance varies on all time scales, seconds to years, and this variation is very dependent on wavelength. During the TIMED mission, the SEE instrument has observed over 200 flares that last from minutes to hours, over 30 solar rotations that have a period of about 27 days, and maximum to moderate conditions during the current 11-year solar cycle. The coronal emissions, such as the Fe XVI 33.5 nm emission and X-rays, vary the most, with variations of a factor of 10 for the larger flares, a factor of two for solar rotation, and a factor of four during the TIMED mission (2 years). The transition region and upper chromospheric emissions, such as the H I 121.6 nm and He II 30.4 nm emissions, vary less, with variations of a factor of 1.2 for solar rotation and a factor of 2 during the TIMED mission. The lower chromospheric and photospheric emissions vary even less. The variations of the solar UV irradiance shortward of 194 nm will be discussed in the context of the TIMED mission.

Keywords: Solar EUV irradiance; NASA TIMED SEE; Solar variability

1. Introduction

The solar ultraviolet (UV) radiation, being wavelengths shortward of 400 nm, is an important source of energy for aeronomic processes throughout the solar system. The solar UV photons are absorbed in planetary and cometary atmospheres, as well as throughout the heliosphere, via photodissociation of molecules, photoionization of molecules and atoms, and photoexcitation including resonance scattering (e.g., see Chamberlain, 1978). The subdivisions of the UV spectral range for this Thermosphere–Ionosphere–Mesosphere Energetics and Dynamics (TIMED) mission discussion include the far ultraviolet (FUV) as the 120–200 nm range, the extreme ultraviolet (EUV) as the 30–120 nm range, the X-ray ultraviolet (XUV) as the 0.1–30 nm range, and X-rays as wavelengths less than 0.1 nm. These definitions of spectral categories are similar to the ISO 21348 definitions except that the ISO 21348 definitions split the XUV and EUV ranges at 10 nm instead of 30 nm. All of the atmospheric processes are wavelength dependent and are expected to be as variable as the intrinsic solar variability at the appropriate wavelengths. Therefore, accurate measurements of the solar UV spectral irradiance, along with an understanding of its variability, are important for detailed studies of the atmospheric processes.

The Solar EUV Experiment (SEE) aboard the TIMED spacecraft is measuring the solar spectral irradiance in the XUV, EUV, and FUV ranges. The SEE includes two instruments to measure the solar UV spectral

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irradiance from 0.1 to 194 nm. The EUV Grating Spectrograph (EGS) is a normal incidence Rowland circle spectrograph and has a spectral range of 27–194 nm with a 0.4 nm spectral resolution. The XUV Photometer System (XPS) includes nine silicon XUV photodiodes with thin film filters deposited directly on the photodiodes. This XUV photometer set measures the solar irradiance from 0.1 to 27 nm with each filter having a spectral bandpass of about 7 nm. A more detailed description of the SEE instrument is given by Woods et al. (1998), and some pre-flight calibration results for the XPS and EGS are given by Woods et al. (1999) and Eparvier et al. (2001), respectively. The in-flight calibrations for SEE include redundant channels used about once a week and calibration rocket flights flown about once a year. As shown in Fig. 1, the SEE solar irradiance results are validated to an accuracy with a relative standard uncertainty of 10–20% at most wavelengths and a measurement precision with a relative standard uncertainty of 1–4% (wavelength dependent).

The TIMED satellite was launched on December 7, 2001, and daily measurements of the solar irradiance by SEE began on January 22, 2002. With SEE only having a single axis pointing platform, the SEE solar observations are limited to about 3 min each orbit with an orbit period of about 97 min. During these 3-min observations, SEE normally obtains twenty 10-s integrations, while the Sun drifts through its ~12° field of view (FOV). The primary data product from SEE is the daily average with flares removed of the solar irradiance from 0 to 195 nm and is called the SEE Level 3 data product. The lower level SEE data products (Levels 1 and 2) are the irradiances at instrument resolution and with the EGS and XPS results in separate files. Whereas, the SEE Level 3 data product combines the EGS and XPS results into a single spectrum in 1-nm intervals and on 0.5 nm centers and is more easily applied for atmospheric studies. The version number for the SEE data products reflects the iteration in changes to the data processing algorithms and/or calibration parameters. The latest SEE data product is Version 7, first released in July 2004, and includes improved corrections for instrument responsivity changes and includes the higher time cadence (3-min orbit averages with flares included) data from SEE that are named the Level 3A data product. The range of the solar UV irradiance in the SEE Version 7 Level 3 data product is shown in Fig. 2. The solar variability observed by SEE during the first two years of operations include several moderate and large flares over periods of seconds to hours, several solar rotational cycles over a typical period of 27 days, and the change from solar maximum conditions to moderate conditions during the 11-year solar cycle. A few of these results concerning solar variations are discussed in the following sections.

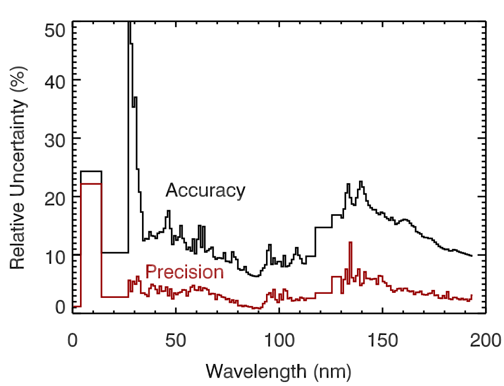

Fig. 1. The relative standard uncertainties of the accuracy and precision for the SEE solar irradiances are shown as a function of wavelength for the SEE Level 3 data product on day 2002/039. The SEE Level 3 data product, being the daily average irradiance, is derived from about 200 10-s solar measurements.

2. Solar variability

The Sun varies on all time scales and the amount of variability is a strong function of wavelength. In the visible portion of the spectrum where the photospheric emissions dominate, the intrinsic, relative solar-cycle variability is on the order of 0.1%. Moving into the middle ultraviolet (200–300 nm), the amount of radiation decreases rapidly while the relative variability increases by an order of magnitude due to lower chromospheric emission contributions. Further into the FUV and EUV, the amount of radiation decreases further while the solar cycle variability continues to increase with the magnitude of the variation for transition region and upper chromospheric emissions approaching a factor of two, and finally to an order of magnitude variations for the high temperature coronal lines that primarily dominate in the XUV range. The solar variation is highly dependent on where in the solar atmosphere that the emission arises, and thus the solar variation does not follow a smooth function in wavelength.

Solar radiation below 200 nm consists of emission lines superimposed on the rapidly declining continuum as can be seen in Fig. 2. These emission lines arise in higher temperature layers of the outer solar atmosphere under non-LTE conditions and are strongly related to the magnetic activity of the Sun as seen, for example, in plage regions and the active network. It is known that these emission lines exhibit large amplitude variability during an 11-year solar cycle, while the underlying FUV continuum portion is far less variable. The XUV region is dominated completely by emission lines, primarily coronal lines that may vary by orders of magnitude during an 11-year solar cycle. Short-term variations, lasting from minutes to hours, are related to eruptive phenomena on the Sun; intermediate term variations,