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The Mg II Index: A Proxy for Solar EUV

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Abstract.
This paper shows that the Mg II core-to-wing ratio is a better proxy for Solar Extreme Ultraviolet (EUV) radiation, between 25 and 35 nm than is the F10.7 index. The He II 30.4 nm solar emission, by itself, is an important source of energy for the upper atmosphere. We will compare the NOAA Mg II Index and the F10.7 Index to the He II 30.4 data taken with the CELIAS/Solar EUV Monitor (SEM) on the Solar and Helospheric Observatory (SOHO).

1. Introduction

Solar EUV radiation is one of the primary energy inputs to the thermosphere and ionosphere. Absorption of EUV photons by O, O_2, and N_2 in the atmosphere above 100 km is responsible for most of the heating in the thermosphere. The EUV photons also ionize the neutral atmosphere, forming the ionosphere. Solar EUV flux, along with high latitude joule heating and tidal and gravity wave forcing from below, comprise the three major forcing functions of the upper atmosphere.

The solar EUV flux changes by factors of 2 to 10 across the spectrum from solar minimum to solar maximum. These changes produce large changes in the neutral and electron density and temperature of the upper atmosphere above 200 km. Figure 1 shows the solar spectrum [*Tobiska,* 1991] for solar minimum and solar maximum (top curves) and the resulting heating rate from 100 to 600 km altitude as a function of wavelength (bottom curve). This plot shows that up to 30% of the atmospheric heating is from the He II 30.4 nm line.

Based on satellite and rocket observations of the solar EUV spectra, *Hinteregger*, [1976] and *Hinteregger* [1981] derived empirical formulae for solar EUV emissions using the F10.7 index as the primary input parameter. Similar models of solar EUV flux were developed by *Tobiska* [1991] and *Richards et al.*, [1994],. A more sophisticated model of the EUV spectrum of the quiet sun was developed by *Warren et al.,* [1998].

There is strong correlation between the F10.7 index and the upper atmospheric density [*Hedin,* 1984], and for many applications the F10.7 index is a reasonable proxy for solar EUV flux. However, as models of the ionosphere and thermosphere improve and as datasets get better, the errors introduced by using the F10.7 index in models become significant. In fact, by replacing the F10.7 index with the Mg II Index, the US Air Force reduced their long-term errors in satellite drag calculations by 13% (*Marcos, Private Communication*). In a similar study of the short term variability in satellite drag, *Thuillier et al.,* [2000] reduced the RMS error in their satellite drag calculations by 20-40%.

The Solar EUV Monitor (SEM), part of the Charge, Element, and Isotope Analysis System (CELIAS) suite of instruments on the Solar and Heleospheric Observatory (SOHO) satellite has been measuring the disk- integrated absolute solar EUV flux since December 1995. This constitutes one of the longest sets of solar EUV data and the first to span the full dynamic range from solar minimum to solar maximum.

In this report, we compare the SEM 30.4 nm channel EUV data to the F10.7 index and to the NOAA Mg II Index [*Viereck and Puga,* 1999]. We show that the Mg II Index provides a considerable improvement over the F10.7 index as a proxy for the solar 30.4 nm flux. In addition, we identify a "real-time" proxy for the solar EUV based on the Mg II Index.

2. Data Sets

F10.7 Index. The F10.7 radio emission is measured by the National Research Council of Canada

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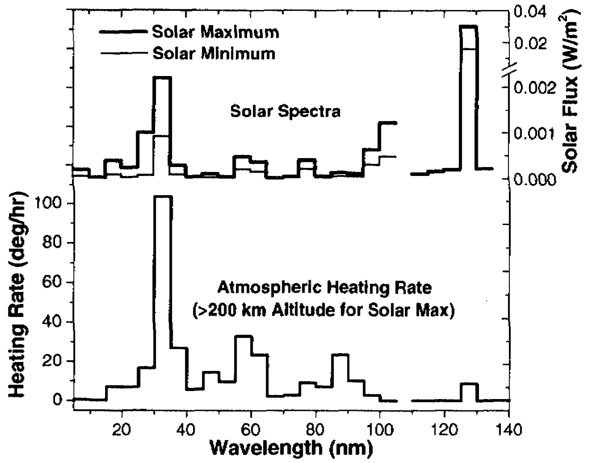

Figure 1. Solar spectra (top curves) for solar minimum and solar maximum and the resulting atmospheric heating rate for solar maximum (bottom curve). Note that the 30.4 nm He II emission produces much of the heating.

from which a daily F10.7 value is determined. The F10.7 emission originates in the chromosphere and lower corona of the sun and has been a standard for solar variability for many studies of Earth's middle and upper atmosphere. Models of solar EUV irradiance (*e.g.* [*Hinteregger,* 1976]) use F10.7 and the commonly used Mass Spectrometer/Incoherent Scatter Radar (MSIS) [*Hedin et al.,* 1977] uses F10.7 as the solar forcing function. The values used for input into these models are the daily and the 81-day running mean of the F10.7. We will use the combined $F10.7+F10.7_{avg}$ in our comparisons of solar irradiance and irradiance proxies.

Mg II core-to-wing Index. The Mg II core-to-wing index was originally proposed by *Heath* [1986] and is derived by taking the ratio of the h and k lines of the solar Mg II emission at 280 nm to the background solar continuum near 280 nm. The solar Mg II feature is measured operationally on a daily basis by NOAA spacecraft. The Mg II lines are of chromospheric origin, and the Mg II ratio has been shown to be an excellent proxy for many UV emissions [*Cebula et al,* 1992]. Mg II data from several NOAA satellites were originally combined to form a single time series by *Donnelly et al.,* [1994] and the time series was extended to 1998 by *Viereck and Puga* [1999]. Using this technique, the version 2.0 data from the Global Ozone Monitoring Experiment (GOME) [*Weber et al.,* 1998] have been added to the Mg II time series to create a single time series covering the period November of 1978 to June 2000, referred to here as the NOAA Mg II Index. The combined data set is available at www.sec.noaa.gov.

SOHO SEM data. The SOHO SEM instrument is a highly stable transmission grating EUV spectrometer [*Ogawa et al.,* 1993], and provides the full disk solar irradiance within an 8 nm bandpass centered at 30.4 nm. The He II 30.4 nm line contributes about 50% of the total signal in the SEM data which is similar to the contribution to atmospheric heating by the He II 30.4 nm line especially near solar minimum. Since the launch of SOHO, there have been three sounding rocket calibration under-flight measurements of the 26-34 nm solar flux. Using these rocket flights for cross calibration, the absolute solar EUV flux in the spectral range from 26-34 nm (the 30.4 nm channel) has been determined to an accuracy of $\sim$10% and a precision of $\sim$1% [*Judge et al.,* 1999].

3. Comparisons and Correlations

F10.7 and SEM 30.4:. Figure 2 shows the F10.7 and SEM 30.4 nm time series plotted together and the correlation is quite good. The rise of solar cycle 23 is quite clear, and the 27-day period associated with the solar rotation is also evident in both time series. The correlation coefficient for these two data sets is 0.983. Note that the correlation coefficient between the daily F10.7 and SEM 30.4 nm values is 0.959, so combining the 81-day smoothing and the daily F10.7 time series improves the correlation. In these comparisons, the correlation is perhaps artificially high, since the dynamic range of the entire four-year period is quite large and will dominate over the short-term correlations. For example, the correlation coefficient between the SEM 30.4 nm data and the daily F10.7 for the solar minimum period from 1 January 1996 to 1 July 1997 is 0.698, indicating significantly poorer correlation for short period variations near solar minimum.

There are other differences between the two time series shown in Figure 2 as well. Note that the F10.7 appears to have a lower limit near solar minimum. From the beginning of the data set through mid 1997, the F10.7 curve is essentially flat with small peaks associated with the 27-day cycle. The SEM 30.4 nm curve has a more pronounced minimum in late 1996 and a larger amplitude 27-day cycle near solar minimum.

Mg II Index and SEM 30.4. The initial comparison between the SEM 30.4 nm data and the daily Mg II Index showed very good correlation, resulting in a correlation coefficient of 0.981 (Figure 3). The Mg II Index tracks the SEM 30.4 nm data better than the F10.7 index. While the overall correlation coefficient is similar to that of the two time series in Figure 2, there are periods when the Mg II Index is a much better proxy for the He II 30.4 than is F10.7. Around solar minimum for instance, the Mg II Index does not flatten and the 27-day cycle variations do not disappear.

Closer examination showed that the raw Mg II Index actually has larger amplitude 27-day cycles than the SEM 30.4 nm data. It was found that a 13-day running average of the Mg II Index produces the best correlation with the SEM 30.4 nm data. Figure 3 shows the two data sets plotted together. The correlation between these two data sets is a remarkable 0.996.

Real-Time EUV Proxy. In order to use the Mg II index as input for "real-time" applications, a modifi-

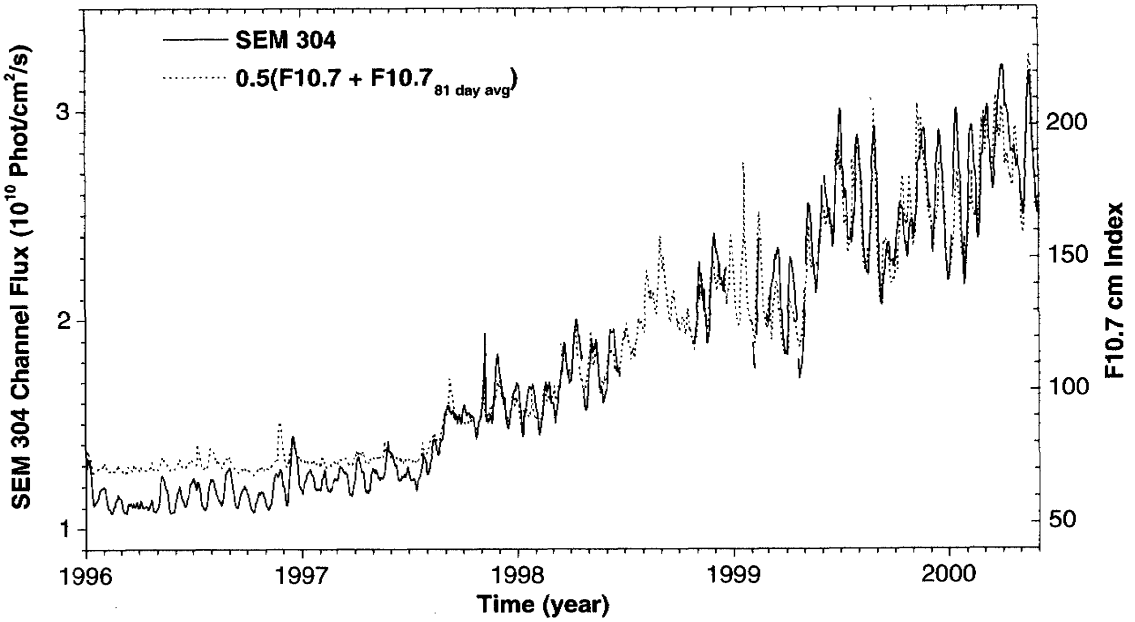

Figure 2. F10.7 cm index compared to the He II 30.4 nm flux. Note that while the agreement is good, there are significant differences especially near solar minimum.

cation to the above algorithms needs to be made. Since the best agreement with the SEM 30.4 data was found to be a 13-day running average of the Mg II index, there would always be an 8-day lag. It should be noted that the typical use of the F10.7 index uses a 81-day running average, which delays the output of the proxy by 40 days.

To overcome this, an alternative method of smoothing is required. We combined the real-time daily value of the Mg II index with an average of the previous 29 days. The average of the previous 29 days maintains the long-term trends in the data but smoothes over the 27-day cycle. By minimizing the RMS difference between the time series, the best result was obtained with the equation EUV $\text{Proxy}_{realtime} = 0.6$ Mg $\text{II}_{daily} + 0.4$ Mg $\text{II}_{29-day\ avg}$. The correlation between the time series calculated with this formula and the SEM 30.4 data for the same 4-year period used in this analysis was 0.991

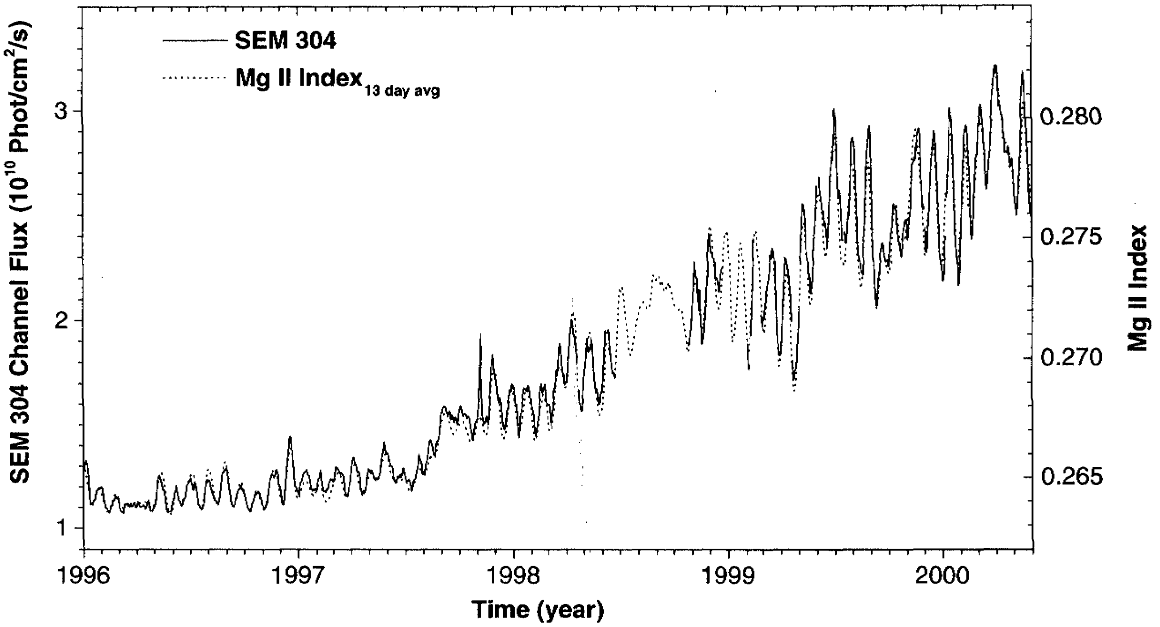

Figure 3. Mg II Index compared to the He II 30.4 nm flux. Note that there is significantly better agreement than with the F10.7 comparison in Figure 2.

which is essentially the same as using the 13-day running mean.

4. Conclusion

The CELIAS/SEM instrument on the SOHO spacecraft has been measuring the He II 30.4 nm solar emission. We have shown that the Mg II Index has a higher correlation with the SEM 30.4 nm channel data than the F10.7 and therefore would provide a better proxy for the EUV. We have found that a 13-day running average of the Mg II Index provides the best correlation with the SEM 30.4 nm channel data and results in a correlation coefficient of 0.996. In addition, we have defined an algorithm by which a real-time proxy for the solar EUV can be calculated using the Mg II Index. This real-time algorithm is based on a combination of an average of the last 29 days of the Mg II Index and the daily value. Using this formulation, we achieved a correlation coefficient with the CELIAS/SEM 30.4 nm channel data of 0.991. The Mg II Index should provide a better proxy for solar EUV forcing of the thermosphere and ionosphere.

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