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FINAL REPORT

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STUDIES OF SOLAR EUV IRRADIANCE FROM SOHO

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INTRODUCTION

We have studied EUV time series produced by both the Solar EUV Monitor (SEM) and by the EUV Imaging Telescope (EIT) with the purpose to better understand their short- and long-term behavior and to extend the SEM measurement data set beyond the times of the actual measurements.

The SEM, a component of the Charge, Element, and Isotope Analysis System (CELIAS) experiment aboard SOHO, measures the EUV irradiance in two wavelength bands, 0.1--50 nm (SEM0) and 26--34 nm (SEM1). The EUV Imaging Telescope (EIT), also aboard SOHO, images the sun at 4 EUV wavelengths (17.1 nm, 19.5 nm, 28.4 nm, and 30.4 nm) using a 1K x 1K CCD. These nominally represent coronal and transition region temperatures of 1M K, 1.5M K, 2M K, and 80,000 K, respectively. Integrated spectral irradiances corresponding to each of these four channels were generated through the efforts of Cook and Newmark outside the scope of this work. This included accounting for bakeouts, flat-fielding, followed by a summing over all of the pixels of the solar disk.

SEM ANALYSIS AND MODELING

The first six years (1996-2001) of SEM irradiance data were analyzed. SEM1 is discussed first because it also is used to produce the measured SEM0 fluxes.

The SEM first order irradiance (SEM1) is produced from the raw measured signals after correction for degradation effects based on measurements by a second SEM which made coincident measurements during several rocket flights. Linear regression fits of SEM1 irradiance time series were performed based on a variety coincident time series, namely, the MgII core-to-wing ratio, the F10.7 radio flux, GOES x-rays, and GOES energetic solar proton fluxes. Although the SUSIM UARS Composite MgII index was the version chosen for this and all subsequent analyses, use of other MgII index versions would give nearly identical results.

SEM FIRST ORDER FLUX (SEM1)

The SEM1 time series was found to be well represented by a linear combination of MgII, its 81-day running mean, F10.7, GOES >10 MeV and >30 MeV fluxes. Over 96% of the SEM1 flux is explained by this five component linear regression model. Heuristically, one can consider that the SEM1 signals are made up by these "components" plus additional unmodeled components (although these components are not orthogonal to one another) and noise. Using the F-test (Bevington, 1969) criterion for the addition of independent variables, all of the listed index and proton flux time series represent statistically significant components of SEM1. The residuals of this fit show relatively little long term trending although some is evident at the start of the experiment in early 1996 when the degradation was the greatest.

Energetic solar protons were not measured by SEM by intention; rather, these protons have penetrated the SEM outer case and interacted directly with the SEM diode detector. One benefit of this analysis is that the regression coefficients multiplied by the GOES proton flux can be subtracted from the SEM1 time series to correct for the proton effect. Although nearly all of this effect was removed, the corrected SEM1 time series still showed (small) jumps on days where the proton flux was large. Discussions with solar energetic particle experts lead us to conclude that higher fidelity measurements, *i.e.* with more energy bins, would allow for better correction of the data. (The effect of the one million mile distance between SOHO and GOES was discounted.) For days having the strongest proton fluxes, *i.e.* those with significant solar proton flares, using the algorithm for filling missing data (see below) was found to be superior to direct subtraction of the solar proton effect.

By far, the largest component of the SEM1 irradiances, of those studied, was the MgII index. The 81-day running mean of the MgII index was also found to be a significant component of the SEM1 irradiances. Use of MgII and its 81-day running mean allows the separation of the long (solar cycle) and short (solar rotation) term components of solar activity so that the amplitude of one is decoupled from the amplitude of the other. Physically, this can be a consequence of differing center-to-limb radiant variations between the quantity being modeled (in this case, SEM1) and that used for modeling (e.g., MgII). Earlier studies have used these two components to model the Ly-a irradiance (Woods, 2000) and the 81-day running mean of F10.7 has been used in the solar 2000 model. Our studies show that the 81-day means of MgII or F10.7 are interchangable and the use of both simultaneously is not statistically significant. This 81-day component (either of MgII or F10.7) of SEM1 is stronger than that of F10.7.

SEM CENTRAL ORDER FLUX (SEM0)

The SEM0 flux represents a very broad aggregate (0.1-50 nm) of EUV and XUV spectral irradiances. The responsivity of the SEM0 channel is generally heavily weighted toward the short wavelengths with the responsivity rising by more than an order of magnitude. The published SEM0 irradiances are a result of both the measured SEM0 and SEM1 spectra and with a great deal of spectral modeling. If we remove the days when SEM1 is strongly affected by energetic protons (see above), the correlation between SEM0 and SEM1 exceeds 0.999; the time series are virtually identical, except that the flux levels of the two are different. Examination of the SEM0 fluxes on days where solar energetic proton levels are high show that their effects propagate through SEM1 into the SEM0 published irradiances.

Examination of the raw SEM0 signals, however, reveals quite different behavior. These signals exhibit very little (if any) degradation indicating that the SEM responsivity degradation is concentrated in the longer wavelengths. Using a similar regression model that was used for SEM1, we found that the SEM0 signals have significant components from MgII, its 81-day average, F10.7, soft (1-8A) and hard (0.5-4A) x-rays (from GOES). Over 98% of the variation of the SEM0 signals is explained by this five component model. Like the signals themselves, the residuals of the fit are flat and relatively untrended.

The F10.7 component of SEM0 is relatively larger and the MgII component is relatively lower than it was for SEM1. Further, if the hard x-ray component is not used, the strength of the F10.7 component increases further. Solar energetic protons have little effect on the SEM0 signals, even as the SEM0 detector is identical to that of SEM1. The reason is that the SEM1 measured signal is very much smaller in absolute terms than that of SEM0, so contaminant energetic protons are a much larger component of SEM1 signal. Although the coefficient of the hard x-ray term is negative, the overall x-ray effect is always positive. An explanation for the negative coefficient of the hard x-ray component is that the photons at the short wavelength end of the soft x-ray spectrum (1-8A) are weighted too strongly for SEM0 indicating that the SEM0 responsivity falls for shorter wavelengths.

SEM RECONSTRUCTED IRRADIANCES

The quality of the fits of the SEM0 and SEM1 allows the generation of fill and extrapolated data based on the regression models. Of course, in the case of SEM1, fill and extrapolated data were generated without the contaminating effects of solar energetic protons. The algorithm for generating fill data improves on the straight use of the regression model by locally (20-30 days) fitting the model SEM0 and SEM1 data to the actual measurements in the region around the days to
be filled. The model data are adjusted to fit the measured data in the time period surrounding each fill day. In this way, the local trends in the SEM data are more faithfully followed.

ANALYSIS OF EIT IRRADIANCES

The EIT images nominally represent irradiances at a range of transition region and coronal temperatures. Visual inspection of the actual images shows the significant differences among them. Spectral modeling of the responsivity shows that FeXV (28.4 nm) channel represents radiation of coronal temperatures at all phases of the solar cycle. The EIT irradiances span a time period from 1 January 1996 to 30 June 2001.

As was the case for SEM, we found that the EIT irradiance time series are better represented by the MgII index than F10.7. MgII also fit better than E10.7, and index developed as a byproduct of the SOLAR2000 solar irradiance model (Tobiska, 2001) although E10.7 does fit better than F10.7. The SEM1 irradiance fits the EIT 30.4 nm irradiance about as well as MgII, despite that it's lower resolution than EIT 30.4 nm. MgII fit better even in the 28.4 nm case where the percentage variation of the EIT 30.4 irradiance was much larger (nearly an order of magnitude) than for MgII.

Multiple regression fits of each of the EIT channels were performed using MgII, its 81-day average, and F10.7. Each of these three indices was found to be statistically significant in the fits of all four EIT irradiance time series. No significant dependence on soft or hard x-rays was found in any of the EIT time series. Each of the four three-component multiple regression models of the EIT irradiance time series (HeII, 30.4 nm; FeIX/FeX, 17.1 nm; FeXII, 19.5 nm; FeXV 28.4 nm) explain more than 97%, 90%, 96%, and 98%, respectively, of the variation in those time series. In each case, the effect of the MgII component was much larger than that of the F10.7 component. In the latter two cases the 81-day running mean of MgII component was also large.

DISCUSSION

The high level of agreement between the SEM1 and EIT 30.4 nm irradiances lend confidence that many of the instrumental effects which affect both instruments have been effectively overcome. The advantage of having accurate irradiances derived from an imaging instrument (in this case, EIT) is that the ultimate causes of irradiance variation will be far more easily discovered because the spatial irradiance contributors are readily available. This work shows that proxy-based models continue to be useful and viable. The F10.7 flux has been widely used as a proxy for EUV and even UV irradiances. The results of this study show that the MgII core-to-wing ratio index models radiant fluxes better than does F10.7 for the solar transition region up to the 2M K corona. The SEM0 results show that F10.7 does better for radiation at much hotter temperatures. Thus, it is recommended that EUV models incorporate the MgII index where it has been shown superior. Further, models using two or three proxies show significant improvements over those relying on a single proxy. It is expected that the upcoming EUV irradiance missions on TIMED and perhaps SDO will further refine these judgements.

PRESENTATIONS AND PUBLICATIONS

1. Floyd, L., D. McMullin, and L. Herring, "Intercomparison of SEM Irradiances and Indices", SOHO-11 Workshop, Davos, Switzerland, 2002 (oral presentation).

2. Floyd, L., D. McMullin, and L. Herring, "Intercomparison of SEM Irradiances and Indices", Proceedings of the SOHO-11 Workshop, ESA, in press, 2002.

3. Floyd, L., L. Herring, J. Newmark, J. Cook, and D. McMullin, "Comparison of EIT Irradiances with SEM Irradiances and Solar Indices", presented to the 4th (virtual) TIGER Symposium and submitted to a special issue of Physics and Chemistry of the Earth, 2002.

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The EUV irradiance central and first order channel time series (COC and FOC) from the Solar EUV Monitor aboard SOHO issued in early 2002 covering the time period 1/1/96-31/1201 were analyzed in terms of other solar measurements and indices. A significant solar proton effect in the first order irradiance was found and characterized. When this effect is removed, the two irradiance time series are almost perfectly correlated. Earlier studies have shown good correlation between the FOC and the MgII core-to-wing ratio and likewise, it was the strongest component of the COC. Analysis of the FOC showed dependence on the F10.7 radio flux. Analysis of the COC signals showed additional dependences on F10.7 and the GOES x-ray fluxes. The SEM FOC was also well correlated with the 30.4 nm channel of the SOHO EUV Imaging Telescope (EIT). The irradiance derived from all four EIT channels (30.4 nm, 17.1 nm, 28.4 nm, and 19.5 nm) showed better correlation with MgII than F10.7.

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