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INTERMEDIATE-TERM VARIATIONS OF CHROMOSPHERIC AND CORONAL SOLAR FLUX DURING HIGH SOLAR CYCLE 21 ACTIVITY

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Abstract. The solar Lyman-α emission, the MgII core-to-wing ratio, $R(\mathrm{MgII}_{c/w})$, the 10.7-cm radio flux, $F_{10.7}$, and the 1-8 Å X rays are compared during high solar cycle 21 activity from 1981-83. Daily variations of the Mg II and Lyman-α ultraviolet (UV) lines are highly correlated. There is moderate linear correlation between these lines and $F_{10.7}$ and poor linear correlation with 1-8 Å X rays. Power spectral analysis indicates that all four fluxes have 27-day periodicities due to solar rotation while the $R(\mathrm{MgII}_{c/w})$ and Lyman-α have noticeable 13-day periods in the datasets. $F_{10.7}$ moderately represents the 27-day solar UV variations and represents to a lesser degree variations shorter than or longer than rotation variations. X rays are not represented by $F_{10.7}$ on intermediate-term or shorter timescales.

Introduction

The lower chromospheric MgII h & k lines at 280 nm vary with solar activity relative to the photospheric continuum emission on the doublet wings. The UV $R(\mathrm{MgII}_{c/w})$ varies in time similar to the 200-285 nm range which heats the stratosphere and photodissociates ozone; it has been used as an index for these solar variations [*Heath and Schlesinger*, 1986]. The Lyman-α is a chromospheric emission line at 121.6 nm which has significant solar activity variations, ionizes the D-region, and is used as an extreme ultraviolet (EUV) chromospheric flux index [*Tobiska*, 1988]. The corona-dominated $F_{10.7}$ also originates in the chromosphere and chromosphere-corona transition region and is often used as an index for solar cycle activity and EUV heating of the thermosphere. The 1-8 Å X ray flux is produced in the hot corona, varies greatly with solar activity, and is an important source of terrestrial D-region ionization during high solar activity.

Short-term, i.e., less than a solar rotation, temporal comparisons of photospheric, chromospheric, and transition region - coronal emissions have been made by Donnelly *et al.* [1983] who noted 13-day periodicity in chromospheric 205 nm flux and differences between emissions due to a central meridian dependence (CMD) during active region evolution. Lean [1987] reviewed short and long-term (annual to solar cycle) UV variability and concluded that the short-term temporal structure is dissimilar to coronally-produced emissions. Wagner [1989] noted solar cycle 1-8 Å X ray variation while Bouwer [1983] observed intermediate-term epochs in 1-8 Å X rays during rising solar activity. Intermediate-term is defined as the timescale of active region evolution and decay, i.e., 1-8 solar rotations. The question examined here is on which timescales does the $F_{10.7}$ represent chromospheric and coronal temporal variations.

Solar Observations

The four solar fluxes compared in this study were measured on a daily basis by ground and satellite instruments in the period between October 8, 1981 and May 19, 1983. $R(\mathrm{MgII}_{c/w})$ was observed by the NIMBUS 7 solar backscattered ultraviolet (SBUV) instrument from November 7, 1978 [*Heath et al.*, 1975] to October 27, 1986. The daily average of several observations of the $R(\mathrm{MgII}_{c/w})$ taken over a few minutes comprise the dataset. The Lyman-α measurements made by the solar ultraviolet spectrometer on the Solar Mesosphere Explorer (SME) satellite began on October 8, 1981 [*Rottman et al.*, 1982] and continue through April 13, 1989 [Rottman, private communication, 1989]. The Lyman-α consists of daily averages of 3-4 measurements per day. The $F_{10.7}$ was first measured on a daily basis beginning February 14, 1947 [*Covington*, 1948] and is available to the present from Ottawa measurements given by the World Data Center. It is a daily flux value based on daily measurements near 1700 UT. The 1-8 Å X ray flux recorded by the GOES series satellites is available from March 21, 1977 [*Bouwer*, 1983] through the present. The GOES 2 daily average data are used in this analysis which extend from January 1, 1980 through May 19, 1983 [*Tobiska*, 1988] and are the daily arithmetic mean of the data collected every 3 seconds by GOES 2. All data are adjusted to 1 AU.

The four solar flux time series are shown in Figure 1. The $R(\mathrm{MgII}_{c/w})$ has approximately one-third of the data missing and has been filled in for display purposes with cubic spline interpolated values. The Lyman-α has only one missing daily value, there are no missing data in $F_{10.7}$, and the 1-8 Å X ray data have eleven missing

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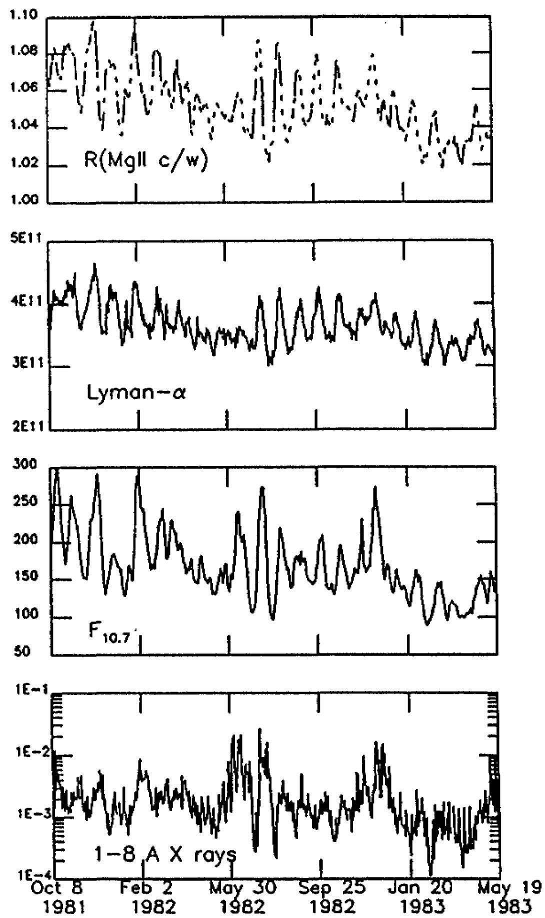

Fig. 1. Four solar emissions between October 8, 1981 and May 19, 1983. Missing data in the $R(\mathrm{MgII}_{c/w})$ time series are shown with dotted lines. Flux units are described in the text.

values. The time units are days between October 8, 1981 and May 19, 1983. The $R(\mathrm{MgII}_{c/w})$ values are dimensionless, having been normalized to the September 1986 (cycle 21 minimum) monthly average. Lyman-α are in units of photons cm^{-2} sec^{-1}, $F_{10.7}$ has units of $\times 10^{-22}$ W m^{-2} Hz^{-1}, and 1-8 Å X rays have units of ergs cm^{-2} sec^{-1}.

Linear Correlations

The results of linear correlations between the four datasets are shown in Table 1 for the daily values and the monthly averages. $R(\mathrm{MgII}_{c/w})$ and Lyman-α have the highest correlation coefficient (0.94) for daily values while Lyman-α and 1-8 Å X ray have the lowest correlation coefficient (0.20). The monthly average comparisons have generally higher correlations than the daily values, except for the X rays.

The linear relationship between the two greatest correlated daily fluxes is

$$\text{Lyman}-\alpha = 1.785 \times 10^{12} R(\mathrm{MgII}_{c/w}) - 1.515 \times 10^{12}.$$

TABLE 1. Solar Emission Comparisons

Abscissa Solar Flux	Ordinate Solar Flux	Correlation Daily value	Coefficient Monthly ave.
$F_{10.7}$	$R(\mathrm{MgII}_{c/w})$	.87	.94
$F_{10.7}$	Lyman-α	.80	.87
$F_{10.7}$	1-8 Å X ray	.46	.45
$R(\mathrm{MgII}_{c/w})$	Lyman-α	.94	.96
$R(\mathrm{MgII}_{c/w})$	1-8 Å X ray	.22	.19
Lyman-α	1-8 Å X ray	.20	.09

The daily value comparisons for $F_{10.7}$ and $R(\mathrm{MgII}_{c/w})$ as well as $F_{10.7}$ and Lyman-α are moderately favorable with highly autocorrelated residuals while there are poor correlations for the remaining cases shown in Table 1. All the datasets have a small secular decrease in total flux for this period of time which is just after the December 1979 maximum and are within the declining phase of solar cycle 21.

Power Spectral Analysis

Power spectral analysis of time series data assumes that the data are stationary, i.e. the statistical properties are invariant with a shift in time. This is not the case with solar flux, particularly with coronal emissions [*Bouwer*, 1983]. As new active regions are born and decay, they often appear at new solar latitudes and longitudes which affect both the observed phases and rotation rates. They generally persist with strong emissions from about four to eight solar rotations where chromospheric emissions persist longer than coronal ones [*Donnelly et al.*, 1982]. At best, solar time series in this study can be considered quasi-stationary where the mean and autocorrelation are slowly-varying. Consequently, we employ running power spectra [*Bath*, 1974] to illustrate the characteristics of chromospheric and coronal flux on intermediate time scales.

The power spectra are calculated by removing long-term trends with a twelfth-order polynomial and determining the autocorrelation using a missing-value algorithm. The FFT is calculated on the autocorrelated data for a 128-day running window which is then shifted 14 days for the next calculation. The running power spectra are then converted to percent power at each frequency where the sum of power at all frequencies is set to unity. A contour algorithm is employed to summarize the results shown in Figure 2.

The following features are observed: 1) to some degree in all the four wavelengths, the stationary portions of the time series appear as three "islands" of power near a 27-day period, 2) the chromospheric emissions show 13–14-day periods while the coronal emissions generally do not, 3) the chromospheric emissions

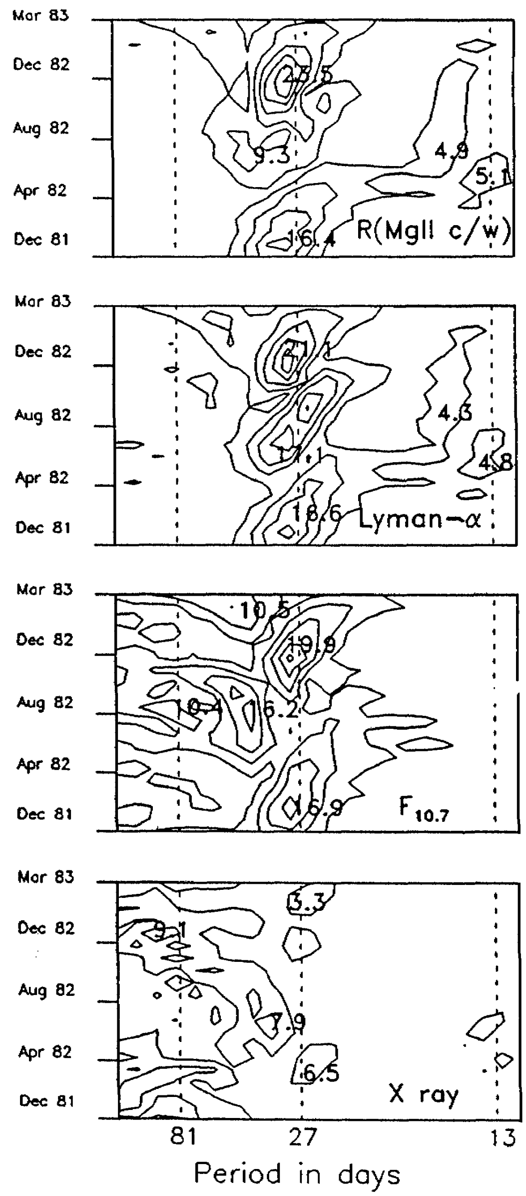

Fig. 2. Running power spectra of $R(\mathrm{MgII}_{c/w})$, Lyman-α , $F_{10.7}$, and 1-8 Å X rays. Each horizontal slice is a typical power spectrum, shifted by fourteen days from the prior spectrum. The ordinates are labeled with dates of the center of the 128-day transform gate. Local maxima are numerically indicated as the percent of the total power. Contour lines start at 2.5% and increment by 4%.

are dominated by a 27-day period while the coronal emissions have significant periods between 36–81 days, and 4) the time interval of relative stationarity for each time series is between 3-6 solar rotations. Three distinct episodes of active region persistence exist for Lyman-α and $F_{10.7}$. The middle region beginning Mar - Jul 1982 for $R(\mathrm{MgII}_{c/w})$ is less clear due to missing data in the time series during a period of numerous small active regions. Nevertheless, where the time series show strong 27-day modulation, the running power spectra shows distinct islands of power, particularly beginning Jul - Nov 82.

The 13-day periods in the chromospheric emissions are not harmonics of limb darkening curves which describe 27-day solar rotations. For example, examination of spatially-resolved data available in *Solar-Geophysical Data (Prompt Reports)* for April 1982 indicates several small active regions roughly separated by about 180° in solar longitude. The 13-day period has also been previously noted in chromospheric emissions [*Donnelly et al.*, 1983]. The $F_{10.7}$ power spectra is a mix of coronal and chromospheric characteristics. The central peak near the May - Sep 1982 time period in Figure 2 has an approximate 46-day period different from the UV lines. It is adjacent to an 81-day period and appears again early in 1983. The 27-day periods in $F_{10.7}$ have the same relative strength as do the chromospheric spectra late in 1981 and 1982. Therefore, the $F_{10.7}$ is similar to chromospheric emissions in the 27-day period power and duration but is dissimilar in longer 81-day and shorter 13-day variations. The percentage of power at periods greater than 27 days for coronal emission results from the lack of persistence of coronal emission from these active regions compared to chromospheric or photospheric emissions [*Donnelly*, 1987]. As a consequence, the X ray time series is strong in longer period intermediate-term variations where rotational effects of individual active regions are secondary. The X rays have 1) weak 27-day periods peaking later than the $F_{10.7}$ or the UV lines, 2) stronger 36 and 81-day periods peaking later than $F_{10.7}$, and 3) a very weak 13-day period coincident with the UV lines.

Discussion

The strong time series and frequency-domain correlations between $R(\mathrm{MgII}_{c/w})$ and Lyman-α result from common regions of formation, i.e. solar plage regions.

TABLE 2. Solar Emission Distinctions

Solar Emission	Linear Correlation	Episode Start	Periods in days
$R(\mathrm{MgII}_{c/w})$	high: Lyman-α mod: $F_{10.7}$ low: 1-8 Å X ray	July '82	27 & 13-14
Lyman-α	high: $R(\mathrm{MgII}_{c/w})$ mod: $F_{10.7}$ low: 1-8 Å X ray	July '82	27 & 13-14
$F_{10.7}$	mod: $R(\mathrm{MgII}_{c/w})$ mod: Lyman-α low: 1-8 Å X ray	June '82	27 & > 27
1-8 Å X ray	low: $R(\mathrm{MgII}_{c/w})$ low: Lyman-α low: $F_{10.7}$	June '82	27, weak 13, & > 27

Chromospheric lines have similar daily and intermediate-term variations due to evolution of the source regions. The distinctions between the emissions are summarized in Table 2.

The limb darkening of active region emission at different wavelengths [*Donnelly et al.*, 1982] explains the dissimilarity in the UV–$F_{10.7}$ and the similarity in the UV–1-8 Å X ray 13-day periodicities. Active regions separated by 180° in solar longitude are strong in chromospheric 13-day periodicity because of this physical separation and limb foreshortening. Active regions are weak in coronal 13-day periodicity since the higher altitude emissions remain in view longer and are not occulted until the source region has moved beyond the limb. The increased power at longer periods in coronal emissions confirms the observation that these emissions tend to peak and decay differently than the chromospheric emissions [*Donnelly et al.*, 1983].

Conclusions

Although one may expect these solar emission variations to be quite similar as a result of solar activity, there are important differences. First, the chromospheric lines of $R(\mathrm{MgII}_{c/w})$ and Lyman-α are highly correlated from daily through intermediate-term timescales. Next, the coronally-dominated $F_{10.7}$ is moderately correlated to these two lines, showing its highest comparison during 27-day variability. $F_{10.7}$ is dissimilar to $R(\mathrm{MgII}_{c/w})$ and Lyman-α in the start and duration of solar rotation episodes composed of several 27-day features. It is also dissimilar in the strength of periods longer than one solar rotation and in the absence of 13-day periodicity compared to $R(\mathrm{MgII}_{c/w})$ and Lyman-α. $F_{10.7}$ tends to peak and decay differently than purely chromospheric lines. Finally, coronal 1-8 Å X rays are not well correlated with any of the other emissions. $F_{10.7}$ is most useful as a chromospheric UV emission index for 27-day timescales and compares less well with these emissions on timescales less than or greater than a solar rotation. $F_{10.7}$ does not represent 1-8 Å X ray flux on the timescales observed.

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