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CHANGES IN PHOTOCHEMICALLY SIGNIFICANT SOLAR UV SPECTRAL IRRADIANCE AS ESTIMATED BY THE COMPOSITE MG II INDEX AND SCALE FACTORS

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ABSTRACT: Quantitative assessment of the impact of solar ultraviolet irradiance variations on stratospheric ozone abundances currently requires the use of proxy indicators. The Mg II core-to-wing index has been developed as an indicator of solar UV activity between 175-400 nm that is independent of most instrument artifacts, and measures solar variability on both rotational and solar cycle time scales. Linear regression fits have been used to merge the individual Mg II index data sets from the Nimbus-7, NOAA-9, and NOAA-11 instruments onto a single reference scale. The change in 27-day running average of the composite Mg II index from solar maximum to solar minimum is approximately 8% for solar cycle 21, and approximately 9% for solar cycle 22 through January 1992. Scaling factors based on the short-term variations in the Mg II index and solar irradiance data sets have been developed to estimate solar variability at mid-UV and near-UV wavelengths. Near 205 nm, where solar irradiance variations are important for stratospheric photochemistry and dynamics, the estimated change in irradiance during solar cycle 22 is approximately 10% using the composite Mg II index and scale factors.

INTRODUCTION

Variations in solar ultraviolet (UV) irradiance have been correlated with changes in stratospheric ozone and temperature on short timescales of days to weeks [*e.g. Keating et al.*, 1987; *Hood and Jirikowic*, 1991] and long timescales of years to decades [*e.g. Keating et al.*, 1981]. Satellite instruments provide the only daily solar ultraviolet observations with wide spectral coverage over long time periods. The NOAA-9 and NOAA-11 SBUV/2 instruments have been making solar observations beginning in March 1985 and December 1988 respectively, and continuing to the present [*Cebula and DeLand*, 1992]. The variation in solar irradiance at 205 nm during solar cycle 21 has been estimated to be 5-8% from SBUV data [*Schlesinger and Cebula*, 1992] and 2-10% from SME data [*Rottman*, 1988]. The magnitude of the uncorrected instrument change in the SBUV/2 data exceeds the estimated solar irradiance variation for long-term use [*Cebula and Hilsenrath, these proceedings*]. The SBUV/2 instruments incorporate an on-board calibration system to monitor changes in diffuser reflectance as a correction to the derived ozone abundances [*Weiss et al.*, 1991]. Successful results from this calibration system only provide information on time-dependent changes in one component of the SBUV/2 optical system, with no provision for the end-to-end calibrations required for accurate long-term solar irradiance observations.

The limitations of current absolute UV irradiance measurements have forced the use of proxy indexes to represent solar UV variability for many purposes, such as atmospheric modelling. The 10.7 cm radio flux ($F_{10.7}$) is frequently used as a proxy for both short-term and long-term solar UV activity [*Keating et al.*, 1981; *Ebel et al.*, 1986; *Chandra*, 1991], but it is not generated in the same layers of the solar atmosphere as ultraviolet radiation in the 200-300 nm wavelength region, which drives stratospheric ozone photochemistry. $F_{10.7}$ is generated in the solar corona, and exhibits different behavior on solar rotational timescales than middle-UV and near-UV solar irradiance generated in the solar chromosphere [*Donnelly*, 1990, 1992]. The equivalent width of the He I 1083 nm line, which does have a chromospheric origin, has been used as an index of solar UV activity since 1974 [*Harvey*, 1984]. However, the He I daily record is only complete at the 60-70% level and contains many data gaps of between 3 and 10 days, which affects studies of short-term variability. In order to identify the contribution of solar activity to stratospheric ozone variations, a proxy index is needed which has a good correlation with solar irradiance variations in the 200-300 nm region, approximately daily measurements to allow accurate characterization of short-term variations, and a data record covering one or more solar cycles to address the magnitude and phase of long-term variations.

The Mg II core-to-wing index of solar variability was first developed for the Nimbus-7 SBUV instrument by *Heath and Schlesinger* [1986], and has been extended to the NOAA-9 and NOAA-11 SBUV/2 instruments [*Cebula et al.*, 1992; *DeLand and Cebula*, 1992]. The Mg II index is defined as the ratio of the irradiance in the core of the unresolved Mg II doublet at 280 nm, which is sensitive to solar activity variations in the chromosphere, to the irradiance in the wings of the Mg II line, which approximates the local photospheric continuum. Previous work [*Heath and Schlesinger*, 1986; *Donnelly et al.*, 1987; *Donnelly*, 1988] has demonstrated that the Mg II index effectively represents short-term solar irradlance variations between approximately 200 and 300 nm. The use of an irradiance ratio eliminates wavelength-independent instrument sensitivity change effects in the Mg II index, and the choice of equally spaced wing wavelengths eliminates most wavelength-dependent effects as well. The absolute value of the Mg II index is strongly dependent on the exact wavelengths and the bandpass of the instrument being used because of the large difference in irradiance between the Mg II line core and the line wings [*Hall and Anderson*, 1988].

MG II INDEX MEASUREMENTS

Long-term data sets of the Mg II index derived from continuous scan solar irradiance measurements over the 160-400 nm wavelength region are now available from three separate SBUV-series instruments. Daily values of the Nimbus-7 SBUV Mg II index time series from November 1978 to March 1987 are shown in Figure 1(*a*). NOAA-9 SBUV/2 Mg II index values between March 1985 and November 1991 are shown in Figure 1(*b*), and NOAA-11 SBUV/2 Mg II index values from December 1988 through January 1992 are shown in Figure 1(*c*). The NOAA-9 Mg II index values are sensitive to instrument noise during periods of low solar activity [*DeLand and Cebula*, 1992]. The NOAA-9 and NOAA-11 Mg II index results presented by *Donnelly* [1988, 1990] are derived from SBUV/2 step scan measurements at selected individual wavelengths about the Mg II line. This product has less sensitivity to irradiance variations in the Mg II line than the continuous scan Mg II index presented here because of the choice of local continuum wavelengths [*DeLand and Cebula*, 1992]. The Mg II index data derived from NOAA-9 and NOAA-11 continuous scan measurements will be used here for continuity with the Nimbus-7 data, which are only available in this format.

COMPOSITE MG II INDEX RESULTS

The variations in nominal Mg II index value between the SBUV and SBUV/2 instruments shown in Figure 1 and the possible variations in Mg II index sensitivity due to instrumental differences must be considered if a single continuous Mg II index data set is desired. Linear regression analysis allows the incorporation of both absolute and relative differences between Mg II index data sets. Relationships between Nimbus-7 and NOAA-9 contemporaneous Mg II index data derived by linear regression, as well as between NOAA-9 and NOAA-11, have been used to construct a composite Mg II index referenced to the NOAA-9 Mg II index scale. Further details of the procedure can be found in *DeLand and Cebula* [1992]. Using a 27-day running average of the composite Mg II index time series to remove the effects of rotational modulation, the change between solar maximum and solar minimum for solar cycle 21 is approximately 8% (Figure 2), where the average of the September 1986 data represents solar minimum values. Solar cycle 22 shows an increase of approximately 9% in the composite Mg II index from solar minimum to solar maximum in early 1989. However, changes in the NOAA-9 wavelength scale may be responsible for approximately 1% of this increase [*DeLand and Cebula*, 1992]. The 2 σ error estimates for each regression fit plotted in Figure 2 indicate that the difference between the magnitudes of cycles 21 and 22 is not statistically significant.

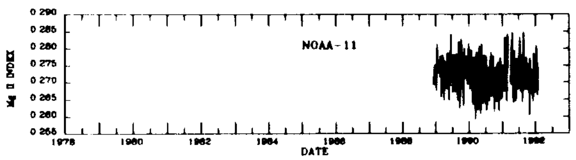

FIGURE 1. Mg II index time series: *(a)* Nimbus-7, *(b)* NOAA-9, *(c)* NOAA-11. The NOAA-9 and NOAA-11 Mg II data have been smoothed with a 5-day binomial-weighted average.

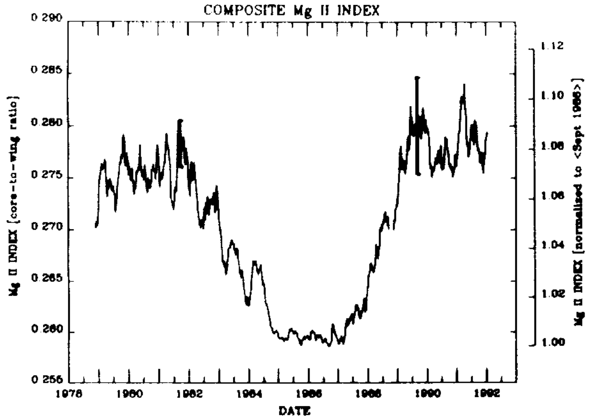

FIGURE 2. The composite Mg II index time series $\mathrm{MgII}_C(t)$ from November 1978 to January 1992, smoothed with a 27-day running average. The right-hand scale uses the average of the September 1986 data as a reference value for normalization. The plotted error bars represent ±2 σ errors.

COMPOSITE SCALE FACTORS

In order to estimate solar variability at other ultraviolet wavelengths using the Mg II index, a set of scale factors must be derived to relate changes in the Mg II index to irradiance changes at each wavelength. Scale factors were developed and presented for the Nimbus-7 SBUV instrument by *Heath and Schlesinger* [1986], and for NOAA-9 SBUV/2 by *Cebula et al.* [1992], based on the strength of 27-day solar rotational modulations. The creation of a composite Mg II index from the Nimbus-7, NOAA-9, and NOAA-11 Mg II index data sets suggests the need for a corresponding composite

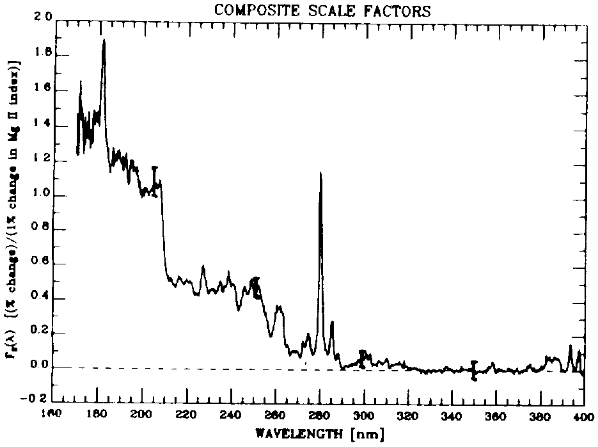

FIGURE 3. Composite scale factors $F_S(\lambda)$ for solar ultraviolet variability in the wavelength region 170-400 nm at 0.2 nm resolution, expressed as percent change in irradiance for a 1% change in the Mg II index.

scale factors data set. Details of the procedure used in deriving the needed scale factors are given in *DeLand and Cebula* [1992]. Figure 3 plots the composite scale factors $F_S(\lambda)$ for the wavelength range 170-400 nm, with 2 σ error bars shown at selected wavelengths. Features exhibiting significant solar variability in Figure 3 include the Al I absorption edge at 208 nm, the Mg II line at 280 nm, and the Ca II K and H lines at 393 and 397 nm. Except for a few identifiable features, the composite scale factors can be interpreted as showing no solar variability beyond 290 nm within the measurement noise. The close agreement in magnitude between the scale factors at 205 nm and the Mg II line supports the suggestion that the similar brightness temperatures of these features will lead to similar responses to irradiance changes [*Heath and Schlesinger*, 1986].

Some question exists as to the validity of estimating long-term irradiance variability using the Mg II index scale factors, which are derived from short-term variations. The relative strength of rotational modulations between different wavelengths appears to be constant during the solar cycle [*Heath and Schlesinger*, 1986]. Predictions of long-term solar irradiance changes using the Mg II index and scale factors will only be in error if the relationship between long-term and short-term variability at a given wavelength differs significantly from the relationship for the Mg II index. The estimated variability of solar irradiance at 205 nm using the scale factors in Figure 3 is up to 7% over a solar rotation, and approximately 9.8±0.7% (95% confidence level) during solar cycle 22, based on the 27-day running average of the composite Mg II index shown in Figure 2. The estimated solar irradiance change at 205, 250, and 300 nm from 1978-1992 using the composite Mg II index and scale factors is shown in Figure 4, with error bars representing the 95% confidence limit in the derived scale factors. A similar analysis by *Lean* [1991] using the He I 1083 nm equivalent width data as an index of solar UV activity yields comparable results.

CONCLUSIONS

Understanding of the variability of solar UV irradiance is recognized as a critical element in determining long-term ozone changes. The composite Mg II index provides a solar UV proxy indicator that is directly related to wavelengths affecting ozone, and avoids instrument change effects which prevent the use of absolute irradiances. Scale factors derived from rotational modulation amplitudes allow estimates of irradiance changes at mid-UV wavelengths from changes in the Mg II index. The composite Mg II index and scale factors are available on CD-ROM from NSSDC [*Larko and McPeters*, 1992]. Additional SBUV/2 instruments planned for launch at approximate 2-year intervals through the year 2000 offer the opportunity to construct a valuable long-term record of solar middle ultraviolet variability.

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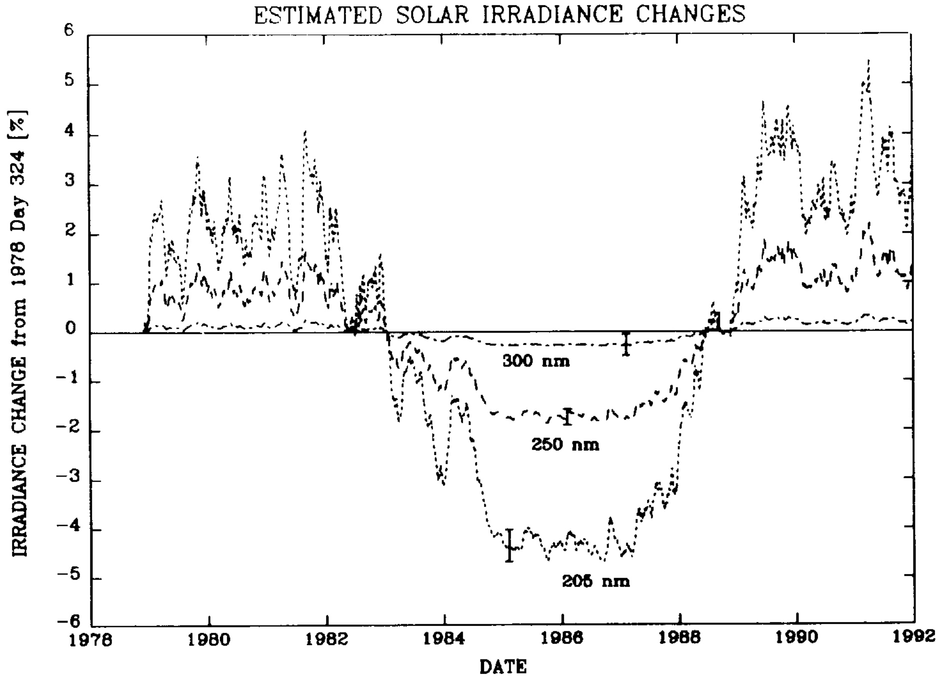

FIGURE 4. Estimated solar irradiance change at 205, 250, and 300 nm during 1978-1992, computed from the composite Mg II index and scale factors.

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