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AFGL-TR-88-0301

AD-A201 707

Instrumental effects on a proposed Mg II index of solar activity

L. A. HALL, and G. P. ANDERSON

Air Force Geophysics Laboratory, Hanscom AFB, Bedford, MA. 01731, *U.S.A.*

Received December 7, 1987 ; revised April 7, 1988 ; accepted April 14, 1988.

ABSTRACT. The Mg II resonance lines near 280 nm have been proposed as a monitor for solar activity in the ultraviolet, particularly for the region around 207.5 nm. Balloon measurements in 0.01 nm resolution are used to investigate the dependence of the proposed index on the characteristics of the measuring instrument. It is shown that for measurements using instruments with low spectral resolution, the value of the index is very sensitive to individual instrument characteristics, and that therefore scale standardization is difficult to maintain.

Annales Geophysicae, 1988, **6**, (5), 531-534.

1. INTRODUCTION

The Mg II resonance lines at 279.6 nm and 280.3 nm in the solar spectrum exhibit emission cores in the centers of their deep absorption profiles, as can be seen in figure 1. These line cores are emitted from the lower chromosphere, above the temperature minimum in the solar atmosphere (Ayres and Linsky, 1976). As chromospheric emissions, these cores show a pronounced solar activity effect, unlike the photospheric emissions forming the line wings (Hall and Anderson, 1984).

Heath and Schlesinger (1986) have proposed that this Mg II doublet be used as an index of solar activity, particularly for the region shortward of the Al I ionization edge near 207.5 nm. In this region the radiation comes from levels in the solar atmosphere similar to those from which the Mg II line emission cores are emitted. They have shown, in measurements made from the NIMBUS 7 satellite beginning in November 1978, that a proposed Mg II index can be successfully scaled to estimate the variation at other ultraviolet wavelengths. The spectrometer on NIMBUS 7 has a spectral resolution of 1.1 nm, and the

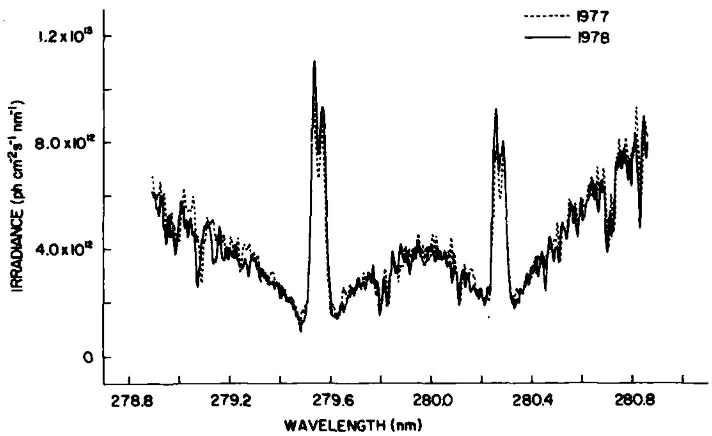

Figure 1

The Mg II *doublet in* 0.01 nm *resolution at* 40 km *in the earth's atmosphere in April* 1977 *and April* 1978. *The horizontal axis gives the wavelength in air. The wavelength scale may be in error by as much as* 0.01 nm *at some points in each spectrum.*

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structure of the Mg II doublet is therefore not resolved. In this report we draw upon measurements made in 0.01 nm resolution (Hall, 1981, 1983 ; Hall and Anderson, 1984) to investigate the effects of individual characteristics of the measuring instrument upon this index. Two additional values of the index are provided for dates prior to the NIMBUS 7 measurements, by using balloon measurements on these dates to create a simulated NIMBUS 7 spectrum. One of these two measurements provides an estimate of the value of the index at solar minimum.

2. MEASUREMENTS

Figure 1 shows the Mg II doublet as measured on 21 April 1977 and again on 19 April 1978 from a balloon near 40 km. On the first date the sun was near its minimum activity level in the cycle just concluded ; the 10.7 cm radio noise flux was $80.8 \times 10^{-22}\ Wm^{-2}\ Hz^{-1}$. On the second date the 10.7 cm flux was 139.5. An increase in the radiation in the emission cores can be seen between 1977 and 1978. The 1977 data were taken from a balloon at about 0.7 km lower in altitude than the 1978 data and a correction has been applied for the additional ozone absorption. The difference in ozone column between the two flights was derived from the measurements themselves (Hall, 1983). Figure 2 illustrates the intensity increase between 21 April 1977 and 19 April 1978 in better detail by comparing the core emissions in the 279.6 nm line alone. The core intensity, integrated over the central 0.12 nm, increased by $11(\pm 5)\%$ between the two dates. The error assigned is a cumulative estimate from all sources.

In an instrument with a spectral resolution coarser than about 0.1 nm, the line cores become blended with the wings and the manifestation of solar activity becomes considerably muted. This is because the wings of the absorption lines are formed in the photosphere and therefore exhibit extremely small (so far unobservable) activity. In figure 3 the balloon data have been degraded in spectral resolution to simulate measurements by instruments with spectral bandpasses of 0.3 nm, 0.7 nm, and 1.1 nm. At 0.3 nm resolution, the broad absorption lines are no longer

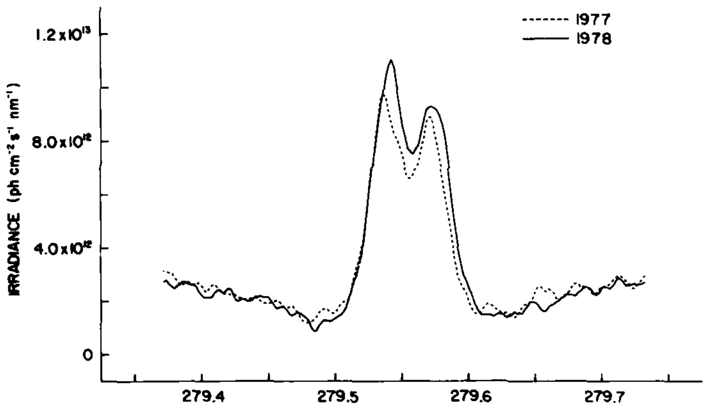

Figure 2
The Mg II line at 279.55 nm, demonstrating the increase in intensity of the emission core between the 1977 and the 1978 measurements. Wavelengths are in air.

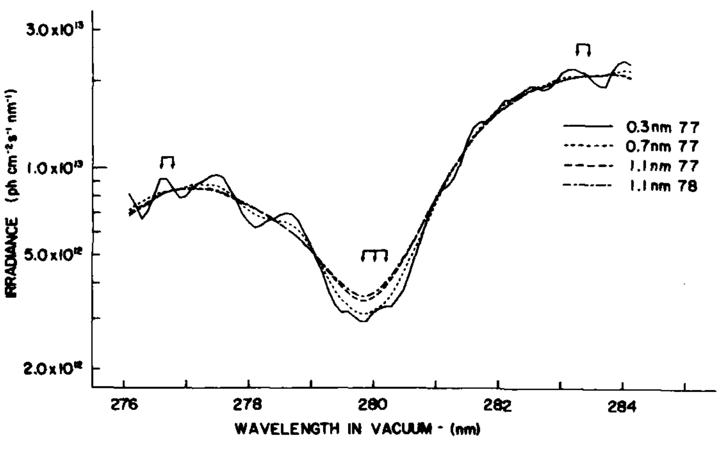

Figure 3
The solar spectrum near 280.0 nm, as it would be recorded by instruments of 0.3 nm, 0.7 nm, and 1.1 nm spectral resolutions. The increase between the 1977 and the 1978 measurements is shown for the 1.1 nm spectrum. The wavelengths are given in vacuum, and arrows mark the wavelengths used in calculating the activity index proposed by Heath and Schlesinger (1986).

resolved, but the line cores can still be separately seen, and at 0.7 nm even the structure of the emission cores has disappeared. Two curves are shown in figure 3 for 1.1 nm resolution, for both 1977 and 1978, to demonstrate the small activity effect (about 3 %) remaining at the center of the unresolved doublet in this resolution. At 1.1 nm resolution, the solar activity effect is smaller than that caused by the resolution changes just discussed. The exceptionally good agreement of the 1977 and 1978 curves in the regions to each side of the central minimum is well within the possible errors of the measurement, and must be considered at least partly fortuitous. A change in these regions is not expected, however, since this part of the solar radiation originates in the photosphere.

The index proposed by Heath and Schlesinger (1986) is in the form of a ratio of measured intensities, in order to avoid a dependence on absolute calibration accuracy. The particular form of the ratio also minimizes the effect of a nearly linear, wavelength-dependent sensitivity drift from which the NIMBUS instrument suffered. The index is calculated as the ratio of the intensity at the center of the line blend to the average of the intensities of the adjacent « continuum » at a distance of 3.3 nm on either side, i.e. :

$$R(\mathrm{Mg\,II}) = \frac{4[I(279.8) + I(280.0) + I(280.2)]}{3[I(276.6) + I(276.8) + I(283.2) + I(283.4)]}.$$

The wavelengths given are those of the vacuum scale. Figure 3 has been marked to show these points of measurement.

The numerical value of this index in the data from NIMBUS 7 ranges from a high of 0.29 at solar maximum to 0.27 at moderate levels of solar activity. This is a small variation, primarily because of the low spectral resolution, but the NIMBUS 7 instrument is sufficiently stable to clearly follow both the 27-day variations and the 11-year cycle variations. However the value of $R(\mathrm{Mg\,II})$ is sensitive to both spectral resolution and wavelength-scale accuracy. These effects were investigated by de-resolving the 0.01 nm balloon data, using triangular smoothing functions to artificially produce spectra that would be measured by matched-slit spectrometers with various spectral resolutions, as in figure 3.

3. RESULTS

Table 1 lists a set of Mg II index values calculated from our 1983 balloon data. The original high-resolution data were smoothed to a series of coarser spectral resolutions before calculating the index. In addition, the index was calculated with the centering of the ratio shifted in wavelength to each side to demonstrate the effects of wavelength errors.

The impact of spectral resolution is apparent in table 1, which shows for example that an index value of 0.24 in 0.7 nm resolution becomes 0.27 in 1.1 nm resolution and 0.32 in 1.5 nm resolution. These changes are larger than the expected cyclic variation from minimum to maximum activity. Therefore, in any comparison of concurrent or successive measurements it is necessary that the spectral bandpass of each instrument (and the instrumental line shape) be accurately known.

Table 1

Mg II *index for* 20 *April*, 1983.

Spectral bandwidth (nm)	Wavelength shift in nm						
	− 0.3	− 0.2	− 0.1	0	+ 0.1	+ 0.2	+ 0.3
0.3	0.237	0.225	0.222	0.222	0.233	0.247	0.259
0.7	0.251	0.243	0.239	0.239	0.243	0.252	0.265
1.1	0.286	0.274	0.267	0.266	0.271	0.282	0.298
1.5	0.328	0.319	0.315	0.315	0.320	0.331	0.347

An error in wavelength scale also has a large effect. An instrument with 1.1 nm resolution may easily have an error of the order of 0.1 nm in its wavelength scale at some points in the spectrum due to a non-linearity in the scan drive, or other cause. Such an error cannot easily be detected in the highly complex blends that the solar spectrum exhibits in low resolution. Table 1 shows the potential effect of an error in wavelength scale. It can be seen, first of all, that an index less sensitive to wavelength scale errors could be formed centered perhaps 0.05 nm to shorter wavelengths than that adopted by Heath and Schlesinger (1986). This option was not open to the NIMBUS 7 instrument because the minimum wavelength step is 0.2 nm. As proposed by Heath and Schlesinger, the index increases about 2 % if a wavelength scale error causes it to be calculated centered around 280.1 nm instead of 280.0 nm for an instrument of 1.1 nm resolution. This 2 % is a sizeable error in measuring an effect that varies by 10 % or less over a solar cycle. The sensitivity to wavelength errors is so non-linear that a 0.2 nm shift swamps the true variation.

Table 2 shows in column 3 the calculation of the Mg II index for the 1977, 1978, 1981, and 1983 balloon measurements. The balloon data have been corrected to the top of the atmosphere for each measurement (Anderson and Hall, 1988) and smoothed to 1.1 nm to match the NIMBUS 7 data. The index reported for coincident dates from the NIMBUS 7 data (Heath, 1987, private communication) is also given. The 10.7 cm flux is listed as an indicator of the solar activity levels. The total range of the Mg II index is 5.5 % for a 10.7 cm flux variation from 80.8 to 191.5. For the two dates on which values are given in both data sets, the absolute agreement is not very good. This is of course not surprising, since errors of this magnitude can be caused by a small wavelength-scale discrepancy, as discussed above, or by a failure to

Table 2

Comparison of indices calculated from NIMBUS 7 *and balloon data.*

Date	10.7 cm flux	Mg II index (1.1 nm)		
		Balloon	NIMBUS 7	Balloon (+ 0.1 nm)
21 April 1977	80.8	0.256		0.263
19 April 1978	139.5	0.265		0.271
22 April 1981	191.5	0.270	0.280	0.278
20 April 1983	126.1	0.266	0.272	0.271

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reasonably duplicate the slit function of the NIMBUS 7 instrument. However, the trend in the variability is well reproduced and a good absolute agreement could be achieved with a shift of only C.1 nm in the index definition. This is illustrated in table 2 by the values in column 5.

4. CONCLUSIONS

It has been demonstrated by Heath and Schlesinger (1986) that their proposed index can be used in the NIMBUS 7 data set to follow solar activity variations. However, extension of the index to data sets obtained with other instruments is likely to be accompanied by normalization problems, perhaps of a non-linear nature. This difficulty is of course made worse by the fact that for the low resolution typical of space instrumentation, the variation of the Mg II index with solar activity is only a few percent. This leaves little room for a normalization error ; and in data sets that do not overlap in time, these problems may be impossible to solve.

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFGL-TR-88-0301	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Force Geophysics Laboratory 6b. OFFICE SYMBOL (If applicable) LIU	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Hanscom AFB Massachusetts 01731-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: 62101F PROJECT NO.: 4643 TASK NO.: 11 WORK UNIT ACCESSION NO.: 06

11. TITLE (Include Security Classification)
Instrumental Effects on a Proposed Mg II Index of Solar Activity

12. PERSONAL AUTHOR(S)
L.A. Hall, G.P. Anderson

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Reprint	FROM ____ TO ____	1988 October 25	4

16. SUPPLEMENTARY NOTATION
Reprinted from Annales Geophysicae, 1988, 6, (5), 531-534

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Solar ultraviolet irradiance, Solar activity, Mg II lines

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL L.A. Hall	22b. TELEPHONE (Include Area Code) (617) 377-3322 22c. OFFICE SYMBOL LIU

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

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