MODELLING SOLAR SPECTRAL IRRADIANCE VARIATIONS
AT ULTRAVIOLET WAVELENGTHS

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ABSTRACT

We examine solar ultraviolet irradiance variations with solar activity by
using a three component model of the CaII K chromospheric emission. This
model, developed from ground based observations of the location, area and
relative intensity of CaII K plage, in conjunction with measurements through-
out solar cycle 21 of the full disc CaII K emission, includes the contribu-
tions to the ultraviolet flux from both plage and active network emission.
Evolution and rotation of the plage regions on the solar disc (as recorded by
the World Data Center of the National Oceanic and Atmospheric Administra-
tion) produce a 27-day modulation of the UV flux. Over longer time scales, such as
the eleven year solar cycle, changes in the active network are an important
source of UV flux variability, and are postulated to arise from the remnants
of decayed magnetic features on the solar disc, and from the temporal
behaviour of ephemeral regions. The model successfully replicates changes in
the Lyman alpha flux related to the 27 day rotation of solar plage, outbreaks
(or rounds) of activity over periods of a year or more, and the growth and
accumulation of active regions over the eleven year solar activity cycle. At
the longer ultraviolet wavelengths, from 200 to 300 nm, the rotation
modulation of the UV flux, observed by the Solar Backscatter Ultraviolet
experiment on the Nimbus 7 satellite, is well described by the model.
Estimates of the magnitude of the solar cycle variability of the UV emission
between 200 and 300 nm are presented but cannot currently be verified by
available observations since the uncertainties pertaining to state-of-the-art
UV flux measurements are larger than the calculated variability. If the cycle
variability of the solar flux at wavelengths between 200 and 300 nm is indeed
of the magnitude predicted by the model, then this emission must be considered
as a source of long term variability in the total solar irradiance.
INTRODUCTION

This paper describes a three component (3C) model of solar UV irradiance variability, derived from ground based observations of solar active regions seen in Ca K emission at 393 nm. In the model, it is assumed that those areas on the solar disc enhanced in Ca K emission are also enhanced in UV emission. There exists an extensive data base characterizing the temporal variation of the Ca K solar emission. Observations of the Ca K emission from the full solar disc (sun as a star) have been made by O. R. White and W. C. Livingston at Kitt Peak (ref. 1), over both the short term (27 day) and longer (11 year) time scales of solar activity, during the current solar cycle. As well, spatially resolved observations of the location, area and relative brightness of the most intense, compact active areas enhanced in Ca K emission (called plage) have been recorded, almost daily, for the past few decades by the WDC/NOAA. It is possible to estimate the magnitude of the UV flux variability from this data base, providing the contrast for active region emission compared to that from the quiet sun, and the center-to-limb variation of the solar radiance at the UV wavelengths are known.

Figure 1 illustrates the similarities between the solar disc viewed at Lyman alpha, at 160 nm and at Ca K. The Lyman alpha and 160 nm photographs were taken by the Transition Region Camera (TRC) described by Bonnet et al. (ref. 2), and have a spatial resolution of about 1". It is evident that plage areas seen in Ca K are also seen as regions enhanced in emission at both Lyman alpha and at 160 nm. Figure 2 further illustrates the similarities between the Lyman alpha emission and the Ca K emission, and also some of the differences. Both photos in Figure 2 have a spatial resolution of about 2".5. The Lyman alpha photo is from Prinz (ref. 3) and the Ca K spectroheliogram is from Mt Wilson: they were taken on July 10, 1972, a period of moderate solar activity during the declining phase of the last solar cycle, #20. Again, those regions brightest in Ca K emission are also brightest in Lyman alpha emission. But note that regions near the limb are more easily observed in Lyman alpha than in Ca K. This is because the Lyman alpha radiance has essentially no center-to-limb dependence, while the Ca K emission at the limb is about half that from the disc center. As well, the contrast for plage emission compared to that from the quiet sun is about 6 for Lyman alpha whereas it is about 2.5 for Ca K. The Ca K plage map in Figure 2 shows the plage regions recorded by the WDC/NOAA for the same day. Only the brightest, most compact, active areas were identified as plage. It is quite evident that a significant fraction of the solar disc was covered by areas of enhanced UV emission that were not recorded by the WDC/NOAA; this is particularly obvious in the Lyman-alpha photograph, and is demonstrated quantitatively in the intensity histogram in Figure 3. By subtracting the quiet sun component (fitted by a Gaussian distribution) from the full distribution, it was estimated that about 25% of the disc, on July 10, 1972, was covered with active network.

It is generally well recognized that the WDC records do not account for all of the active area on the disc. This follows from the work of Sheeley (ref. 4), and Harvey and Martin (ref. 5), who made detailed studies of both Ca K spectroheliograms and magnetograms. To model properly the temporal behaviour of the UV flux it is necessary to know the true fraction of the
solar disc covered by active area at different times throughout the solar cycle. We can obtain a quantitative estimate of this active area fraction by using the WDC/NOAA records in conjunction with the measurements of the Ca K flux from the full solar disc. If we calculate the Ca K flux from the quiet sun plus the WDC plage areas and subtract this from the measured full disc flux, the difference can be attributed to the Ca K emission from active areas other than those recorded by the WDC, a component which we call "active-network" (see Figure 3).

**VARIABILITY OF THE CaII K EMISSION WITH SOLAR ACTIVITY**

Figure 4 shows the behaviour of the Ca K line index from both the center of the solar disc and from the full solar disc, throughout the current solar cycle, as measured at Kitt Peak by White and Livingston (ref. 1). At the center of the disc, in selected quiet regions, the Ca K emission remains constant throughout the cycle, implying the constancy of the quiet sun emission (ref. 6). In contrast, the Ca K emission from the full solar disc increases from solar minimum (1976) to solar maximum (1979). At least part of the Ca K flux variability (on both short and long times scales) evident in this figure can be attributed to the evolution and rotation of the plage areas. Figure 5 illustrates how solar rotation generates changes in the projected plage area, when viewed from earth, for a few active rotations near the maximum of the current solar cycle. We can thus expect the Ca K (and also the UV) flux from the full solar disc to be modulated by solar rotation. Such rotational modulation has indeed been observed in full disc solar observations, and is illustrated in Figure 6, for both the Ca K and the Lyman alpha flux. The Ca K data were taken by W. C. Livingston at Tucson, and the Lyman alpha data by G. J. Rottman on the LASP/SMM satellite (ref. 7). Using the plage area data from the WDC/NOAA, we can calculate the expected magnitude of the solar flux modulation due to solar rotation, for both the Ca K and Lyman alpha emission, if we know the quiet sun emission from the center of the disc and from the full solar disc, the center-to-limb variation, and the contrast for plage emission relative to that from the quiet sun (ref. 6).

For the Ca K line, the center-to-limb variation has been measured by White and Suemoto (ref. 8). Data for the Ca K plage contrasts are shown in Figure 7, as a function of the observed relative brightness listed in the WDC records. The contrast for "observer intensity" $T_{\text{obs}} = 3$ is from the measurements of Lemaire et al. (ref. 9), and the relative variation of plage contrast with observer intensity was provided by R. Hedeman.* Calculated plage related variations are compared with full disc Ca K observations in Figure 8. It is evident that the relative changes with solar rotation are well reproduced but the absolute magnitude of the calculated plage emission is significantly less than that measured from the full solar disc. Of course, by increasing the plage contrast and/or the area by a factor of about 2 (see ref. 6), it is possible to increase the calculated plage flux, but then the observed rotation modulation would be overestimated. So the good fit of the rotation modulation suggests that the plage contribution to the full disc Ca K emission can be successfully reproduced using the WDC plage area together

* Private communication, 1982.
with independently measured plage contrasts. If the Ca K emission from the quiet sun (undisturbed chromosphere) remains constant throughout the solar cycle, as evidenced by the center disc observations of White and Livingston (ref. 1 and Figure 4a), then it is necessary to postulate a source of enhanced Ca K emission, additional to plage, in order to explain the full disc Ca K flux variability measured over the solar cycle (Figure 4b).

The work of Harvey and Martin (ref. 5) suggests that ephemeral regions (ER), which are small bi-polar regions not large enough to be identified as plage, may be an important source of enhanced Ca K flux. We can estimate their contribution to the full disc Ca K emission as follows. Figure 9 (from ref. 5) shows the growth of a typical ER, observed with about 2''5 resolution. The top graph shows the total magnetic flux from the ER and the bottom graph shows the area, typically equal to about $3 \times 10^8 \text{ km}^2$, or 0.01% of the solar hemisphere. If we divide the total flux by the area, at various times during the lifetime of the ER, we can estimate the magnetic field to be around 55G. The Ca K emission from an active region increases linearly with magnetic field. According to Skumanich, Smythe and Frazier (ref. 10), the magnetic field in the Ca K network, which has a contrast of about 1.27, is 26G, and a magnetic field of 55G corresponds to a contrast of 1.42. Note that this value is much less than the plage contrast of 2.3 (see Figure 9). We can also estimate, from the results of Harvey et al. (ref. 11) the fraction of the solar disc covered by ERs at different times throughout the solar cycle. In 1970 there were, on average, 373 ERs present on the disc, decreasing to 179 in 1973 and to 88 in 1975. With a typical area of 0.01% of the solar hemisphere, about 3.7% of the hemisphere was covered with ERs in 1970, decreasing to 1.8% in 1973 and to 0.9% in 1975. Thus the average number of ERs appears to vary in phase with the solar cycle, allowing us to parameterize the ER fractional hemispheric area in terms of the total plage area on the disc, smoothed over three rotations, and calibrated by the 1970, 1973 and 1975 ER counts. This is consistent with the identification of the ERs as simply the small scale end of a broad spectrum of active regions. Using this parameterization, and a contrast of 1.42, we can estimate the ER contribution to the full disc Ca K flux at different times throughout the current solar cycle.

In Figure 10, the calculated Ca K emission from both plage and ERs is shown. The combined flux from both plage and ER still underestimates the observed full disc flux near solar maximum; for this reason we have assumed additional enhanced Ca K emission from the Ca K network (with contrast 1.27) which is formed, for the most part, around the borders of the supergranule cells. On the same figure, the combined emission from both plage, ER and network is compared with the full disc measurements made at Kitt Peak. This figure demonstrates that, having obtained reasonably good estimates of the plage emission (as verified by the agreement between the calculated and observed magnitude of the rotational modulation, see Figure 7), it is not possible to reproduce the solar cycle variability of the full disc Ca K flux measured at Kitt Peak without postulating the existence of additional sources of enhanced Ca K emission. In summary, by using the full disc Ca K flux data measured at both Tucson and Kitt Peak, it has been possible to first calibrate the WDC plage areas and then to estimate how the fractional area of this additional source, which we have called active network (ER plus additional
network area), varies throughout the solar cycle.

Our estimate of the magnitude of the fractional active network area present on the solar disc at different times throughout the solar cycle is very sensitive to our calculation of the Ca K rotation modulation. Figure 8 demonstrates that we have reproduced the daily rotational modulation observed during 1982 by W. C. Livingston at Tucson. However, it is evident in Figure 10 that the full disc Ca K observations made by White and Livingston (ref. 1) at Kitt Peak are not fit particularly well by the calculated rotation modulation. Differences between the Tucson daily Ca K data (Figure 8) and the Kitt Peak solar cycle measurements (Figure 10) are being investigated. Meanwhile, it is important to recognize that increasing the calculated rotation modulation, to better fit the Kitt Peak data in Figure 10, would lead to a decrease in our estimate of the active network fractional area, which we use in the following sections to examine solar variability at other wavelengths.

LYMAN ALPHA FLUX VARIABILITY

Assuming that active areas (both plage and active network) enhanced in Ca K emission are also enhanced in emission at other UV wavelengths, we can now investigate the solar flux variability at other UV wavelengths, for example at Lyman alpha (ref. 12). We can estimate the plage and network contrast at Lyman alpha from Prinz's (ref. 3) intensity distribution of Lyman alpha radiances (Figure 3); there the plage-quiet sun contrast is about 6 and the network-quiet sun contrast is about 2 (see ref. 12 for a more detailed discussion). Figure 11 compares the calculated Lyman alpha flux variation throughout 1979 with data from Hinteregger's AE-E satellite experiment (ref. 13), which measured the Lyman alpha flux from the full solar disc. The rotation modulation is well reproduced, in both magnitude and period, and the 3C model estimates the rotation modulation better than other models based on either the 10.7 cm flux or the sunspot number. This is discussed in more detail by Donnelly et al. in another paper in this volume (ref. 14). Figure 12 illustrates that over the longer time scale of the solar cycle, when the active network emission becomes as important as the plage emission, the model also reproduces the observed changes in the Lyman alpha emission, both from the AE-E satellite, and the LASP rocket measurements. This is discussed further by Lean and Skumanich (ref. 12). We note that Vidal-Madjar's (ref. 15) Lyman alpha model, derived from the OGO-5 Lyman alpha observations, is also a three component model: Vidal-Madjar found that the observed Lyman alpha flux variation was better correlated with a three component approach, than with a two component model based only on daily solar activity indices. The models of Cook et al. (ref. 16) and Bossy and Nicolet (ref. 17) are both two component models. The comparisons, in Figures 11 and 12, of the calculated Lyman alpha flux variability with the available full disc Lyman alpha observations illustrate that the 3C model developed from the Ca K observations can be extended to model the variability of other UV emissions from the sun.

ESTIMATING SOLAR FLUX VARIATIONS: 200 - 300 NM

Of special importance for interpreting the observed changes in the spectrally integrated (total) solar irradiance is the variability in UV wave-
lengths longer than 200 nm. The solar flux between 200 and 300 nm represents about 1% of the total solar irradiance; solar flux variability at these wavelengths is generally assumed to be negligible in terms of its contribution to changes in the total solar irradiance. Recent observations by the Solar Backscatter Ultraviolet (SBUV) experiment on the Nimbus 7 satellite (ref. 18) provide evidence that the solar flux at wavelengths at least as long as 260 nm exhibit a variation associated with solar rotation (ref. 19); we can expect an even larger variation over the 11 year solar cycle. The magnitude of the solar cycle variability at these wavelengths is not well known, because measurements of the absolute solar UV irradiances are difficult and have large uncertainties, typically greater than 15% - 25%; however, we can use the three component model to estimate the probable magnitude of this variability (ref. 20).

An example of the rotation modulation of the solar flux at 205 nm, detected by SBUV during 1979, is shown in Figure 13. The projected plage area is also shown and demonstrates the high degree of correlation between the two. The data presented sample a period near solar maximum: the rotation modulation is smaller at times near solar minimum since there are fewer plages on the disc. The rotation modulation also decreases with wavelength: the bottom graph in Figure 13 shows the ratio of the maximum to minimum flux for three distinct solar rotations labelled A, B and C in the graph above. At 200 nm there is about a 3% modulation which drops sharply to 1% at wavelengths longer than 207.5 nm, the aluminium I ionization edge. A plateau of constant modulation extends up to about 251 nm, the onset of Mg I ionization, with the variability decreasing at longer wavelengths. The Mg II lines, which are of chromospheric origin, can be seen to be more variable than the surrounding continuum emissions, which originate in the photosphere. Assuming that the rotation variability at these longer UV wavelengths is, like that at the shorter wavelengths, associated with changes in the plage area on the solar disc, we can use the short term SBUV observations to obtain estimates of the plage contrast (i.e. that factor by which the plage emission must be enhanced above the quiet sun emission in order to explain the observed rotation modulation). The plage contrasts calculated in this way are shown in Figure 14. At the shorter wavelengths, less than 210 nm, there is good agreement with the measurements reported by Cook et al. (ref. 16). At wavelengths longer than the Al I edge, Cook et al. set the plage contrast to unity. However, if the plage emission at these wavelengths was not enhanced above that from the surrounding quiet sun, rotation modulation would not be detected, contrary to the SBUV observations.

In addition to plage contrasts, we also need to estimate the network contrasts. Figure 15 shows the calculations by Herse (ref. 21) of the contrast of bright structures on the disc, at wavelengths from 200 nm to 100 \( \mu \)m. This empirical facular model was derived by Herse from a statistical study of facular grains, observed at wavelengths 200 nm, 210 nm, 310 nm and 460 nm with high spatial resolution (0'.5) in regions of the solar disc covered by predominantly non-plage features. Herse's observations indicated that the excess emission from network features was about half that from the brighter plage areas. In Figure 15 the mean contrasts (averaged over position on the solar disc) for the mean facular grains, degraded to a resolution of 2'.5 (by dividing by a factor of 3, as recommended by Herse) can be seen to be in good
agreement with the network excess emission (contrast -1) determined as half that from plages, where the plage contrasts are those in Figure 14 (i.e. deduced from the SBUV short term observations). Other estimates of facular contrast, averaged over all wavelengths, reported by Foukal (ref. 22) and Hoyt and Eddy (ref. 23), are provided in Figure 15 for comparison.

Having estimated the active region contrasts (both plage and network) at these longer UV wavelengths, we can estimate the flux variability over the solar cycle associated with the increase in the active area fraction, as determined from the analysis of the Ca K data. These estimates are shown in Figure 16. The minimum expected variability (dotted line) is that due to the increase in plage regions alone (from 0 to 5% of the disc, as documented by the WDC/NOAA). The cycle variability due to twice the plage area is also shown (dash-dot line). The solid line is the variability expected from an increase of 0 to 5% of the disc fraction covered by plage plus an increase of 0 to 40% of the hemispheric fraction covered by active network. The calculated variability is 25% at 200 nm, dropping to 10% at wavelengths from 210 to 250 nm and to only a few percent at 300 nm. The radiation at 300 nm originates in approximately the same region of the solar atmosphere as does the visible continuum radiation at 500 nm (ref 24). Ground based observations indicate that the variability at 500 nm is no more than a few percent (ref. 16) which is quite consistent with these calculations. In Figure 17 the calculated variation in the solar flux from 200 to 205 nm, for the period around the maximum of the current solar cycle, is compared with available observations. The rocket data are from LASP (refs. 25,26) and Mentall et al. (ref. 27). H refers to the SBUV measurement at the time of launch (ref. 19). The error bars indicate limits of +/− 10% which is an optimistic estimate of the accuracy of these experiments. This figure demonstrates that the measurement uncertainties are greater than the calculated variability and therefore the available observations can neither confirm nor refute the model calculations.

TOTAL SOLAR IRRADIANCE VARIABILITY

The change, from solar minimum to solar maximum, in the total energy radiated from the sun at wavelengths between 200 and 300 nm is calculated by the 3G model to be of the order of 0.5 to 0.7 Watt/m² (14.7 Watt/m² in 1976; 15.4 Watt/m² during December 1979). This represents about 1/20th percent of the total solar irradiance. To put this in the perspective of the total solar irradiance (S) variations, Figure 18 compares the calculated variability over the wavelength interval 200 - 300 nm with the variability due to sunspot blocking, as calculated by Hoyt and Eddy (ref. 23). The important point is that, while the UV variability may not contribute significantly to the short term changes in the total solar irradiance, the active network term means that, over longer time scales, in order to properly interpret changes in S it may be necessary to understand the UV variations. Note that the cavity radiometers used to measure the changes in S (refs. 28, 29) are sensitive to radiation at wavelengths longer than about 180 nm, so they are capable of detecting any changes in the UV emission at wavelengths from 200 to 300 nm. Even if the magnitude of the UV variability is half that suggested by these calculations, it still must be considered as a source of variability in S. It is not yet known how the total solar irradiance varies over the solar cycle –
whether it is out of phase with the sunspot number, as suggested by Hoyt and Eddy's (ref. 23) calculations, whether it is in phase, as suggested by Reid and Gage's (ref. 30) analysis of the variations in the height of the tropical tropopause, or whether there is no average change; this is a very fundamental gap in our understanding of the causes of the total solar irradiance behaviour. Figure 19 illustrates this current confusion. The model of Hoyt and Eddy (ref. 23) considers primarily the effects of sunspot blocking on the total solar irradiance whereas Schatten et al. (ref. 31) include a greater contribution from the faculae (average effect at all wavelengths). They determined the magnitude of the faculae contribution by fitting a model to the daily ACRIM data (ref. 29) and then extrapolating the fitted parameters to longer time scales (i.e. the solar cycle). This is, in effect, a two-component approach to faculae emission. Recall, however, that, at least at the UV wavelengths, because of the three components, the daily variations due to plage regions underestimate the variations over the solar cycle.

A potential problem with extrapolating total solar irradiance models derived from daily observations over time scale of many solar cycles, is that the sunspot areas and the facular areas may not necessarily vary proportionately. Figure 20 shows, from the work of Brown and Evans (ref. 32), that the 11 year cycles in the sunspot areas are modulated somewhat differently than the 11 year cycles in the facular areas. Assuming that the changes in the UV are better represented by the faculae areas than by sunspot areas, we see that the relative effects of the UV flux variability and of sunspot blocking may well be different during different solar cycles. Although Figure 21 (ref. 20) is quite speculative, it provides an attempt to predict quantitative changes in the total solar irradiance due to both enhanced UV emission from active regions and sunspot blocking; these calculations are compared with a model based on simple sunspot blocking and minor facular emission (ref. 23).

CONCLUSIONS AND FUTURE WORK

The 3C model calculations described above represent an attempt to understand solar variability at different ultraviolet wavelengths. As emphasized by Foukal (ref. 22), to properly understand the causes of total solar irradiance variability requires an understanding of spectral irradiance variability. Our present knowledge of solar ultraviolet irradiance variability over the solar cycle, especially at wavelengths between 200 and 300 nm, is inadequate for understanding variations in the total solar irradiance. The 3C model calculations suggest that active area emission other than that from plage areas is an important source of UV flux variability and that this variability may need to be incorporated in models of $S$ if the total solar irradiance variability is to be properly interpreted.

Uncertainties in the Ca K plage contrasts and areas generate uncertainties in our calculation of the rotation modulation of the Ca K flux, and hence in the deduced fractional active network area. Our estimates of the UV flux variability which use Ca K active network fractional area data as input reflect these uncertainties. Little is known about the average (in a statistical sense) contrasts for plage and network emission at either Ca K or the UV wavelengths. Intensity distributions of the entire solar disc at Ca K
and at different UV wavelengths are needed to provide these data. Quantitative information about the spatial correlation between the Ca K and UV active areas is essential for improving the 3C model.

The lack of statistically averaged data characterizing surface inhomogeneities on the solar disc when observed at Ca K is an unnecessary source of uncertainty in our model calculations. Although Ca K spectroheliograms are made routinely, little effort has been directed towards defining the intensity distribution function for the whole solar disc (in the same way that Prinz, ref. 3, characterized the Lyman alpha emission). Analyses of Ca K spectroheliograms, similar to that shown in Figure 3 for Lyman alpha, would yield valuable information about the average Ca K plage contrasts and areas, as well as estimates of the fractional network area and contrast, at different times throughout the solar cycle. Such data would provide an important check on the active area parameters used in the model calculations of both the Ca K and the UV flux variability.

Continued observation and interpretation of the Ca K emission from the full solar disc, during the descending phase of the current solar cycle, is essential for improving our understanding of the evolution, with solar activity, of magnetically active features on the solar disc. Although during the rising phase of the solar cycle, the Ca K flux was well correlated with the plage index (a measure of projected plage area weighted by a relative brightness estimate), Keil and Worden (ref. 33) have recently reported that during 1980 and 1981 the Ca K emission did not decline as rapidly as the plage index. They offer the explanation that, although the amount of plage is decreasing, the field associated with the plage is not dissipated; rather it is rearranged into the network where it can still contribute to an enhanced calcium emission but not show up as plage. Alternately, the plage may simply become too diffuse to be included in the somewhat subjective plage index. Both of these scenarios are consistent with our findings that, in order to explain the observed full disc Ca K flux variations, it is necessary to invoke a source of Ca K emission additional to the measured plage areas. However, while our parameterization of this third component (the active network term in our model) as a linear function of the total plage area on the solar disc, smoothed over seven rotations (see ref. 6 for a more complete discussion), appears quite satisfactory for the ascending phase of the solar cycle, a more detailed quantitative prescription of magnetic flux breakup and loss by reconnection and submergence is probably required to better model the Ca K flux variations during the descending phase of the solar cycle.

In order to utilize the Greenwich faculae record, which extends back to 1905, the correspondence between total plage area on the disc, and the white light faculae seen on the limb must be quantitatively established. This will allow a more reliable calculation of the UV fluxes during past times.

During the next few years data from the Nimbus 7, SMM, and SME satellites should provided more simultaneous, continuous and reliable data for both the total solar irradiance and the spectral irradiance variability than have yet been available. Such data will enable improvements to be made in models such as the three-component model described in this paper, and allow solar variability models to better reconstruct the past history of the solar irradiance.
REFERENCES


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LIST OF FIGURES

1. Photographs of the sun on 23 September 1980 at a) Lyman alpha (ref. 2), b) CaII K and c) 160 nm in the UV continuum (ref. 2). The Lyman alpha and 160 nm data have a spatial resolution of about 1" while that of the Ca K data is 2".5.

2. Photographs of the sun on 10 July 1972 at a) Lyman alpha, 121.57 nm (ref. 3) and b) CaII K, 393.3 nm (R. Howard, private communication). The CaII plage areas recorded by the WDC/NOAA are identified in c). The spatial resolution of both photographs is about 2".5 X 2".5.

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20. a) Model calculations by Hoyt and Eddy (ref. 23) of the total solar irradiance variations due primarily to sunspot blocking for the period 1870 to 1980, compared with
   b) the temporal variations in the sunspot area and faculae area reported by Brown and Evans (ref. 32), for the same period.

21. Calculated relative changes from 1905 to 1975 in a) the UV (200 to 300 nm) and sunspot blocking, together with b) the resulting prediction for the total irradiance variations, compared with the (predominantly sunspot blocking) model of Hoyt and Eddy (ref. 23).
SOLAR DISC: 10 JULY 1972

a) Lyman α

b) Ca II K

c) Ca II K Plage Map
Figure 3
Figure 6

- Ca II K1.0 - Tucson
  Lyman alpha - SME

R = 0.9
Figure 7
- Full Disc, Measured at Kitt Peak
- Full Disc, Measured at Tucson
- Plage, Calculated from WDC/NOAA data

Figure 8
Typical Ephemeral Region Growth (2" 5"

Major Axis (10.4 km)

Figure 9

(a) 54G

(b) 56G

62G

0 4 8 6 2 4 2

Time

1800 2000 2200

Total Flux (10^20 mx)

(10^8 km^2)

Area

0.01% of solar hemisphere
Figure 10

K1.0 Index: Solar Cycle 21

- CaK full disc data
- Active network + ephemeral regions + plage
- Ephemeral regions + plage
- Ephemeral regions
- Quiet sun

Year

K1.0 (A)
Figure 12
Figure 13
Figure 16

283
Figure 17
a) UV (200 - 300 nm)

SUNSPOT BLOCKING

b) SUNSPOT BLOCKING & UV (200 - 300 nm)
Figure 20
Figure 21

a) uv (200-300 nm) and Sunspot blocking

b) uv (200-300 nm) and sunspot blocking

Hoyt and Eddy
DISCUSSION OF LEAN PRESENTATION

ZIRIN: Why not just measure the UV pictures to find the feature contrasts?

DONNELLY: No one ever bothered to, they never saw it was important.

SCHATTEN: The UV contribution is in the model since the model is fit to the ACRIM data.

LEAN: If you only fit to the daily variations, that leaves out the slowly varying components.
HEATH: Our results are from an instrument which really was not designed to do solar physics. The primary objectives of these measurements are to detect changes in the ultraviolet albedo of the Earth in the ozone absorption region, to detect long-term changes in the stratospheric ozone, and to identify the physical mechanisms which are responsible for these long-term changes. Nevertheless, the instrumentation has several advantages. We had to have scattered-light rejection by six orders of magnitude over about 200 angstroms. We had to have extremely high radiometric stability since we were trying to measure albedo changes of half a percent. We had to have extremely high wavelength precision, stability as well as linearity.

There are two parts to the solar problem. One is to determine whether or not there is any evidence of changes taking place, and the other is to interpret the physical processes responsible for the changes. For our purposes the biggest problem is in what the Sun is doing in the ultraviolet; the ozone exists solely because of ultraviolet radiation coming from the Sun.

Here you see the solar spectral irradiance data with good evidence for 27-day variability. I will concentrate on the modulation during one solar rotation period, the ratio of maximum to minimum. Our data begin one year prior to solar maximum and continue three years after. I am going to describe briefly the work that we're doing in trying to check long-term changes in the solar spectral irradiance, as well as a series of studies of the aluminum ionization edge where you have the least change in the emitting region in the solar atmosphere. We take the ratio of magnesium II to magnesium I as a temperature indicator by comparing it with a blackbody spectrum.

There are a number of interesting features which I will show you; one has to do with the ratio of the enhancement of that region to that of Mg I and the other one has to do with the appearance and disappearance of the Fe I emission lines and the behavior of the aluminum ionization continuum and [some] emission lines.

The instrument that we use to make these measurements has a 10 angstrom spectral bandpass. It's fortunate that the dynamic range required to make solar measurements in the region from 1600 to 4000 angstrom is exactly the same as what we need to measure the atmospheric albedo, so it makes an ideal instrument. Just to give you an idea of the quality of the daily measurements, we make a measurement approximately once per day at the northern hemisphere and this is the solar flux at 205 nm, 2050 angstrom, which is the short wavelength [band]. . . . [of] observation [averaged] over a year, this is the 27-day peak and these are the 13 1/2 day peaks that correspond to active regions about 180° apart in solar longitude and, as Jack Harvey mentioned earlier, [these go from modes in which you] have a typical 13 1/2 day forcing of having two active longitudes, and then it will suddenly make a transition over to only one active longitude; but this gives you some idea of the stability of the data and don't attach any significance to the long term changes for that is on instrumental [effect]. Now if we look at the Mg II h and k lines, that is . . . at 2800 angstrom, here again we see these series of 13 1/2 day strong signals [with] a 27-day modulation. This has an instrumental dip connected into it, but you can sort of think of it as
though [you've] subtracted out part of this.

I want to concentrate more on the modulation with time, and one of the things that comes in, which should be rather obvious, is that over this 4-year period, that there are periods when the amplitude of the modulation of the Mg II, singly ionized is the same all the way up to 1982. In terms of the rotational modulation, there has been this very high level of solar activity until the day when Jack showed this curve; this curve is the 205 nm long-term changes. But this is different than the Mg II h and k. We've taken out, to the best of our ability, the instrumental changes in the instrument's sensitivity [and you can think of it in terms of a series of residuals that are] departures from a slowly-varying...drift..., but the surprising thing is, apart from the repeating of the series of peaks of very strong 27-day variation, the maximum in UV radiation occurs in late 1981, [whereas] sunspot maximum was in 1979. An this feature becomes stronger and stronger as you approach the region of the temperature minimum. At first, as I said, I didn't believe this; I thought it was just some artifact; now I'm beginning to believe that there may be some substance to this delayed UV radiation. This is very important as far as understanding what's producing the long term behavior in ozone. People over a number of years have made studies of the relationship between ozone and sunspot number, and for the most part the effect has more or less fallen by the wayside because you observe that the maximum effect in the long term changes in the ozone occurred one to two years after sunspot maximum and for this reason it was thrown out. But now, based on what we're seeing, and what Jack was showing in the He I line, perhaps [one] should reconsider this question.
EDITOR'S NOTE: Dick Willson made a second presentation, for which the text and figures are incorporated into his paper published in these proceedings. The discussion for this presentation follows here.

DISCUSSION OF WILLSON PRESENTATION

HUDSON: Will the calibration of the ACRIM spin-stabilized data get better - do you plan to re-analyze the calibration?

WILLSON: Yes, but I am pleased with the calibration I am using now.

FOUKAL: In the spin-stabilized data you don't use the reference provided by the back of the shutter. Also, what about the time constants involved in the measurement?

WILLSON: We do not use data that do not give a minimum duration of solar viewing. It's reasonable to say that our criterion is not definitive; the analysis will be sharp enough to... As a matter of fact, in the spin mode, the instrument looks into cold space once for each solar sample, which is a far better calibration.

FOUKAL: And that correction is well enough known that it's small compared to the error bar that you have there?

WILLSON: Oh, that correction is about 0.06%.

FOUKAL: Then the error bar on that correction makes a negligible contribution.

DONNELLY: Now that you leave your shutter open all the time, do you see any evidence of rapid degradation relative to the reference?

WILLSON: No, we don't.

SOFIA: I would like the other modelers to produce a residual graph the way we have done, to see if there is any sustained discontinuity roughly at 0.2% decrease after the new mode of operation that might indicate something instrumental as opposed to something that's changing on the sun.

WILLSON: I've noticed from your results yesterday, where you said you did see what could be interpreted as a level shift, however, your level shift occurred some time in February, about 6 months too late.

SOFIA: Yes, on the other hand the residuals are pretty large. But it did seem to be a few months later.

ZIRIN: I guess the long-term data will really settle this question of sunspots versus plages. Either it will relax to the average between them, or it will relax to a quiet sun value....

SCHATTEN: If Hickey's data had a general trend...

WILLSON: That brings me to my next point.
MOORE: What if you just fit '81 to '82 and forget about 1980 and 1981; what kind of slope do you have?

WILLSON: I haven't done that; it would be interesting to do.

DONNELLY: What if you just do the fit for the days that you both have data and not fill in any data which makes a controlled bias, do you still get as good an agreement?

WILLSON: That's something worth doing; I haven't done it.

HUDSON: We could take your data and just throw out the days...

CHIPMAN: That's not the same thing, because one of the reasons for this later result is that Hickey's data underweights the latest part of the last year...

WILLSON: You're right Eric, it wouldn't give an accurate representation of the real slope, but Dick's right too in that it would give an estimation of whether or not throwing those out, we both get the same result, albeit not a very interesting one.

SOFIA: Another way of looking, though, is if you divide [it] right there in February - the ACRIM data before and after - there seems to be a shift in level.

WILLSON: Where is this famous shift in levels? I'm not seeing something! (some laughter).

SOFIA: Here it is! The level up here is there! And afterwards it's there! You don't look at the trend, you fit to the first half from there to there, and there it is, and then you look at this one and there it is; it's a bit lower whereas here there is no obvious shift or trend.

CHIPMAN: That's not very fair.

HUDSON: That's not a meaningful statement because of course if there's a trend the means will be different. Is the data powerful enough to support a higher-order fit than a linear trend? With all the noise that's there it is hardly very satisfactory even to do a linear fit.

CHAPMAN: What is the linear trend with time just for the spin-stabilized part of the data?

WILLSON: I haven't separated it out. Just for 1980, it was 0.04% for 300 days, which is 0.05% per year.

CHAPMAN: So it wasn't constant; what was the uncertainty in that? Was that a two- or three-sigma result?

WILLSON: Yeah, at least.
CHAPMAN: So there was already a downward trend, it's dangerous when you're fitting two different slopes that are very small when the signal is that noisy. I just don't think it's valid to try to, with your eye, to fit two things together like that [discussion continues briefly].

SCHATTEN: Perhaps what you could do is a separate analysis up until the time you redid your method of analysis, and then another one afterwards and presumably those two curves would look somewhat similar to what you have ... and that would enable you to see [any change in slope] and would also perhaps give you a feeling for the uncertainty, which you say is only about 0.02% or of that order.

WILLSON: OK, we'll do that.
FINAL DISCUSSION OF GROUND-BASED OBSERVING PROGRAMS

The editors felt that improved ground-based observations could go a long way towards improving the understanding of the variations of solar irradiance on active-region time scales. The improvements probably should include strengthening of the traditional synoptic observing programs, the introduction of new technology in old or new measurements, and a renewed focus on interpretation and theory. The participants in this workshop were therefore urged to contribute brief comments on directions that they felt would be useful. We summarize our own ideas on p. 313 in "A Global Irradiance Program."