TWO-DIMENSIONAL PHOTOMETRY OF ACTIVE REGIONS*

J. K. Lawrence, G. A. Chapman and A. D. Herzog
San Fernando Observatory
Department of Physics and Astronomy
California State University, Northridge

J. C. Shelton
TRW, Inc.

ABSTRACT

We describe a set of two-dimensional photometric images of solar active regions (AR's). Preliminary analysis of the data is described, and estimates are presented of the contribution of an AR to total solar irradiance variations during its 1982 August 3 - 16 disk passage. Results indicate an excess contribution near the limb and a deficit away from the limb. Also apparent is an evolutionary change in the AR which can be represented as a decrease in sunspot area. Future plans are also discussed.

OBSERVATIONS

Our purpose in this contribution is to characterize two-dimensional photometric data we have taken with the San Fernando Observatory (SFO) Reticon, a 512 element linear diode array system, and to describe the results we are now beginning to achieve on the contributions of active regions (AR's) to variations in the total solar irradiance.

The observations are carried out with the SFO 28 cm vacuum solar telescope and vacuum spectroheliograph (SHG). The SHG exit slit is set on a clean continuum portion of the solar spectrum at 6264 Å with a bandwidth of 1.5 Å. This wavelength band was selected for its freedom from both photospheric and sunspot absorption lines. It is also conveniently close to the 6303 Å line used for other studies. The diode array, mounted at the exit slit, produces 512 x 512 pixel images as the entrance slit is swept across an AR. The images are stored on magnetic tape using one of SFO's two Varian 620i computers with 12 bit precision per pixel. With this arrangement the pixel spacing is 0.94" allowing pictures with resolution > 2" and a field of view of 480". The scanning time per picture is 104 sec, and scans can be repeated at intervals as short as 2 min. Typically intervals greater than 20 min were used between scans of a given region, to randomize the signal from granulation patterns. The observations were repeated for up to 4 hours near local noon so that later digital averaging could suppress the effect of transient features and enhance the signal-to-noise ratio of subtle brightness structures. Short calibration scans were included frequently to record both the dark current response of the diodes and sunspot-free photosphere near disk center. The solar limb and nearby sky were observed periodically. Occasionally, observations were made of

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sunspot fine structure with the SFO 61 cm vacuum telescope, which provided a pixel spacing of 0.42". A few observations were made at other wavelengths to obtain color/temperature information on various AR components. These observations were made in the IR at 10000 Å, in the red at 7824 Å, and in the green at 5254 Å. Some AR scans were also made in the Ca II line at 8662 Å.

Except when interrupted by bad weather or equipment failure, observations were made continuously from 1982 July 8 to October 23, a period including 5 solar rotations. Coverage during the full interval was 80/112 days or 71%. Better weather earlier in the summer permitted 87% coverage from July 8 to September 12. On the average, observations were made of ~5 AR's per day (range 0 – 9) with an average of ~5 scans/AR/day. Note that AR's near the limb require fewer scans because of their greater facular contrast coupled with a somewhat lower granulation contrast. Several regions have been observed on as many as four disk passages.

An example of a 512 x 512 digital picture of an AR is shown in Fig. 1.

DATA REDUCTION

Reduction of a digital picture like that in Fig. 1 to a value for the AR's contribution to a solar irradiance deficit or excess requires several steps, not all of which have yet been carried out. For example, no corrections have yet been applied for scattered light or for color differences between AR components. The results presented here must therefore be regarded as preliminary.

Raw data are first corrected for differing responses of the individual array diodes by means of dark (shutter closed) and bright (spot-free, disk center) calibration scans. The quantity (observed – dark)/(bright – dark) is normalized to an arbitrary value of 200 units at hypothetical disk center. Then data are square averaged down to make a 256 x 256 pixel array.

The next series of steps corrects the data for limb darkening. Using Mt. Wilson sunspot drawings a first estimate is made of the location of solar disk center in pixel coordinates. Then each pixel is divided by a calibrated quiet sun (QS) brightness obtained from a Pierce and Slaughter 5th-order polynomial limb-darkening curve (Ref. 1) which has been interpolated to our wavelength (6264 Å). Disk center coordinates are then re-adjusted to give the best fit (flat background), and, if necessary, the zero level is adjusted to bring this level to the arbitrary 200 unit value. After this, pixels with values below, within, or above the range 193 – 207 units (± 3.5% of the average value) are assigned to "sunspot", "photosphere", or "faculae" categories, respectively. This offers a number of quality-of-fit parameters, such as the relative numbers of pixels assigned to the three categories, or the standard deviations of the pixel values within each of the categories. Also, a correction factor is determined to bring the average of the "photosphere" pixels back to 200 units.

At this point it is possible to subtract the theoretical limb darkening from the calibrated data pixels. The residual values are then summed and the result expressed in parts per million (ppm) of the total QS brightness. The process is repeated for up to four same-day pictures of the AR, and an average of the results is obtained.
RESULTS

The procedure we have described was carried out during the passage of Big Bear AR No. 18511 across the solar disk from 1982 August 3 to 16. The results are shown in Fig. 2. The average deficits and excesses are plotted as circles with error bars (σ) signifying the standard deviations of the means of these averages, in ppm of QS. No results are available for August 14 or 16. In cases where no error bar appears, the formal error is smaller than the plotted circle.

Also plotted in Fig. 2 are a number of other measures of the effect of ARs on solar irradiance. All are in the same units. Plotted as small squares (□) are irradiance deficits and excesses for AR 18511 as measured by the SF0 extreme limb photometer (ELP) described in (Ref. 2). Plotted as dots (•) are the sunspots-only (faculae ignored) contributions measured by the ELP. Plotted as x’s (x) are daily values of the AR photometric sunspot index (PSI) based on sunspot areas A, in ppm of the solar hemisphere, published in Solar Geophysical Data and corrected for limb darkening according to

\[ \text{PSI} = -0.164 \ A_\mu(3\mu + 2), \]  

where \( \mu = \cos \theta = (0,1) \) at (limb, disk center). See Ref. 3. Inverted triangles (▽) in Fig. 2 represent differences between the diode array results and a PSI figure based on a constant area sunspot with its area normalized to fit the central meridian data. Right-side-up triangles (Δ) represent the difference between the ELP results and the constant-area PSI values.

DISCUSSION

As can be seen in Fig. 2, the diode array results show contributions to an excess irradiance when the AR is near the limb (\( \mu \leq 0.5 \)) and a deficit when it is away from the limb (\( \mu \geq 0.5 \)). This is expected because of the known enhancement of facular contrast near the limb. The ELP results show greater excesses than do the diode array results. This may be caused in part by the fact that the diode array calculations have been stopped several arc seconds from the limb, so some facular contributions have been left out. We are currently trying to improve limb darkening fits so that this situation may be improved. The ELP – diode array discrepancy on August 5 (\( \mu = 0.56 \)) may be more difficult to reconcile.

Our belief in the reliability of the diode array results is increased by their reasonable agreement with the PSI values from published sunspot areas. It should be kept in mind, of course, that, by definition, PSI can never show an excess irradiance. Note, however, the close agreement of the PSI values with the ELP results with faculae excluded. This indicates that in reconciling results near the limb we will more probably end up adjusting the diode array calculations.

The asymmetry of the diode array deficit about central meridian passage can be interpreted as a decrease with time in the AR sunspot area. Values near the limb appear to be influenced by facular effects, so to study AR

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evolution we here consider only values for August 5 - 13. The deficits are converted to effective sunspot areas by inverting the equivalent of Eq. (1). These areas show a decreasing trend that can be approximated as linear. A regression analysis gives a slope for this of dA/dt = -137 ppm/day = -5 x 10^9 m^2/s. Note that this is about an order of magnitude faster than published decay rates for long-lived sunspots (Ref. 4). This effect, together with the fact that sunspots alone can not show irradiance excesses, is also illustrated by the plot of differences between diode array values (Δ) and ELP values (Λ) on the one hand versus the constant disk sunspot model on the other. The asymmetry illustrates the convolution of AR evolution effects with projection effects in our observations.

Our hope is to be able to separate these effects so that we will be able to determine the dependence of the brightness and color of the various components (e.g., sunspots, faculae) of ARs. We would then hope to be able to determine the contribution of ARs to solar irradiance as a function of their full evolution. We may then be able to determine the relative contributions to energy balance of sunspots vs faculae over the complete lifetime of an AR.

As stated above, we have observations of ARs like 18511 on 4 disk passages, and we have observed regions where ARs have recently disappeared to search for residual faculae. On the other hand, it will be necessary to acquire further multi-color data, and the formidable problems of fitting darkening near the limb and of corrections for stray light have not yet been fully faced.

REFERENCES


2. Chapman, G. A.: Ground-Based Active Region Photometry. Workshop on Solar Irradiance Variation on Active Region Timescales NASA CP , 19 . (Paper of this compilation.)


FIGURE CAPTIONS

1. Diode array digital image of Big Bear AR No. 18511 made 1982 August 8 with the SFO 28 cm vacuum telescope.

2. Contributions to irradiance deficit or excess in ppm due to Big Bear AR No. 18511 during the disk passage of 1982 August 3 - 16. Details are described in the text.