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An Investigation of the Energy Balance of Solar Active Regions Using the ACRIM Irradiance Data

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1. INTRODUCTION

This report fulfills the required submission of a semi-annual progress report under NASA contract NASW-4062, "An Investigation of the Energy Balance of Solar Active Regions Using the ACRIM Irradiance Data". During the reporting period Dr. Larry Petro replaced Dr. Peter Foukal as principal investigator for the contract as a result of Dr. Foukal's leaving his position at A.E.R., Inc. As approved in a letter from the Contracting Officer on September 4, 1985, a portion of the work to be carried out under NASW-4062 has been subcontracted to Cambridge Research and Instrumentation, Inc., which is Dr. Foukal's present place of employment. All work described in this progress report has been carried out in consultation with Dr. Foukal.

2. WORK COMPLETED DURING THE REPORTING PERIOD

2.1 Influence of Faculae on Solar Irradiance

A paper entitled "The Influence of Faculae on Total Solar Irradiance and Luminosity" was completed by Dr. Foukal and collaborator Dr. Judith Lean and will be published in the April 15, 1986 issue of the Astrophysical Journal. That work presents a correlation detected between the irradiance (as measured by both ACRIM and ERB) as corrected for sunspot flux deficit (which is responsible for most of the variance of the uncorrected signal) and both the 205-nm flux (as measured by Nimbus-7) and a photometric facular index. This suggests that faculae contribute significantly to the total solar flux. These cross-correlations, as well as the cross-correlation with the correction itself, are shown in Figure 1. It can be seen that both facular indicators (S_{205} and P_f) provide 25 per cent larger correlation at zero lag than does the sunspot correction and these indicators have non-zero positive-lag cross-correlation, whereas the sunspot correction function has no positive-lag correlation, thereby supporting facular emission as the cause of correlation with the corrected radiances rather than error in the correction. Further measurements demonstrate that faculae and sunspots make approximately equal, but opposite sense, contributions to the total irradiance on an active region time-scale during the spot-maximum year 1980. Arguments are presented that these two contributions are independent, and therefore facular emission is not simply reradiated sunspot-blocked flux.

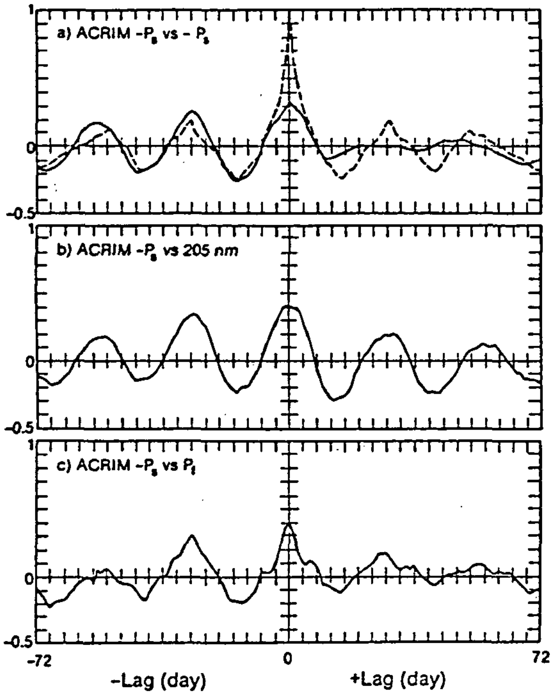

Fig. 1. Cross-correlation functions (solid lines) of sunspot compensated radiance (denoted ACRIM − P_S) vs. (a) − P_S, (b) 205 nm flux, and (c) P_f. The dashed line in (a) gives the autocorrelation function of ACRIM − P_S.

2.2 Model of the Influence of Sunspots on Solar Irradiance

A consultant under the contract, Dr. Eric Graham, has provided a computer program which simulates two-dimensional convection in a compressible, statified medium. This has been successfully run at A.E.R. by Dr. Wei-Hwan Chiang on a Cromemco CS-1, MC68000-based, microcomputer. A velocity field previously calculated by Dr. Graham with an earlier version of the code (J. Fluid Mech. (1975), 70, 689) was reproduced in a verification run on the microcomputer which required 15 CPU-hours and employed a 9 cell by 16 cell grid for the finite difference scheme. This run attained a convective steady state, as demonstrated by the evolution of the Nusselt number shown in Figure 2. The final state consists of two counter-rotating convection cells as shown in Figure 3.

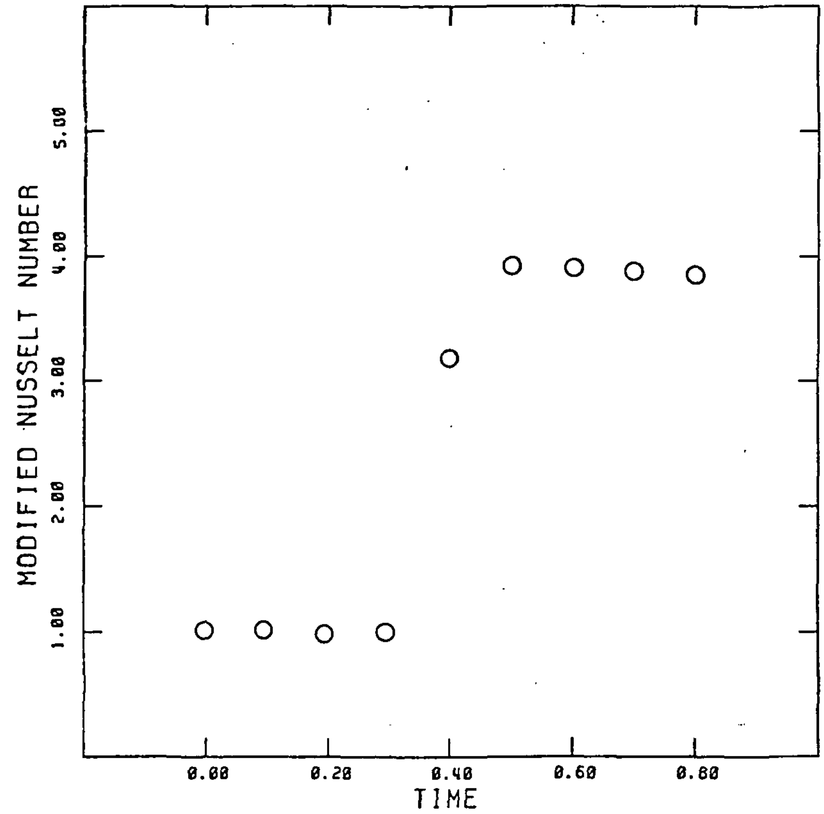

Fig. 2. Evolution of the Nusselt Number during a numerical simulation, using a microcomputer, of two-dimensional convection in a compressible, stratified medium. The computer code was provided by Dr. E. Graham.

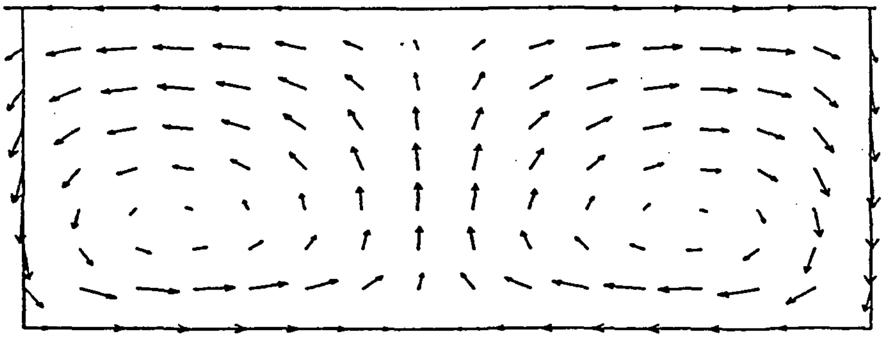

Fig. 3. Velocity field of the steady-state convection for the case illustrated in Figure 2. The grid is 9 cells by 16 cells.

2.3 Observations of the Influence of Sunspots on Solar Irradiance

Equipment has been acquired by Dr. Foukal to perform high-precision, white-light observations of sunspot areas, and procedures were tested during the reporting period, but as yet no measurements have been obtained. These observations were seriously impeded by the lack of sunspots during this time of solar-cycle minimum. Careful comparison of the Questar 3.5 inch aperture and the Unitron 4.0 inch aperture telescopes demonstrated that the Unitron telescope had lower scattered light (a desirable feature for accurate sunspot area measurements), and it was therefore purchased. A 35-mm camera and an evaporated-chromium neutral-density filter are also employed, the latter allowing the full-aperture resolution (1.2 arc-seconds) to be utilized while achieving proper exposure.

An attempt to extract sunspot areas from measurements of film negatives with a computerized P.D.S. microdensitometer at American Science and Engineering was deemed unsuccessful due to the large amount of computer post-processing required. It has therefore been decided to employ a simple measurement procedure which consists of first locating the spots with respect to a heliographic grid and then graphically measuring the spot area from calibrated enlargements of the original photographic negatives.

Improved CCD observations of sunspot bright rings have been obtained in a cooperative arrangement with the National Solar Observatory at Sacramento Peak. These new observations include better photometric correction calibration scenes which should provide greater photometric accuracy. Previous observations which we obtained did not have sufficiently good auxiliary photometric calibration that low-contrast, large-scale features could be securely measured.

2.4 Observations of Large-Scale Heat-Flow Inhomogeneities

Dr. Chiang and Dr. Petro began the analysis of observations of large-scale convective heat inhomogeneities which were obtained in May 1985 at the Vacuum Telescope of the National Solar Observatory on Kitt Peak, Arizona. These observations benefitted from the lack of sunspots, which has hindered the observations described in Section 2.3. The original data consist of 120 monochromatic scans of the Sun, each comprising 512 by 2048 pixels. Data compression of the original, fine-scale observations, geometric rectification, transformation to a standard metric, and photometric correction have been accomplished for a 5-day subset of the 16-day observation. An example of such corrected, standard-metric intensity residuals are shown in Figure 4. The intensity range of the grey-scale image is ±2 per cent of the intensity at center of the disk and the pixel size is 8 arc-seconds square. Features visible include granular noise, faculae near the limb, and the limb itself.

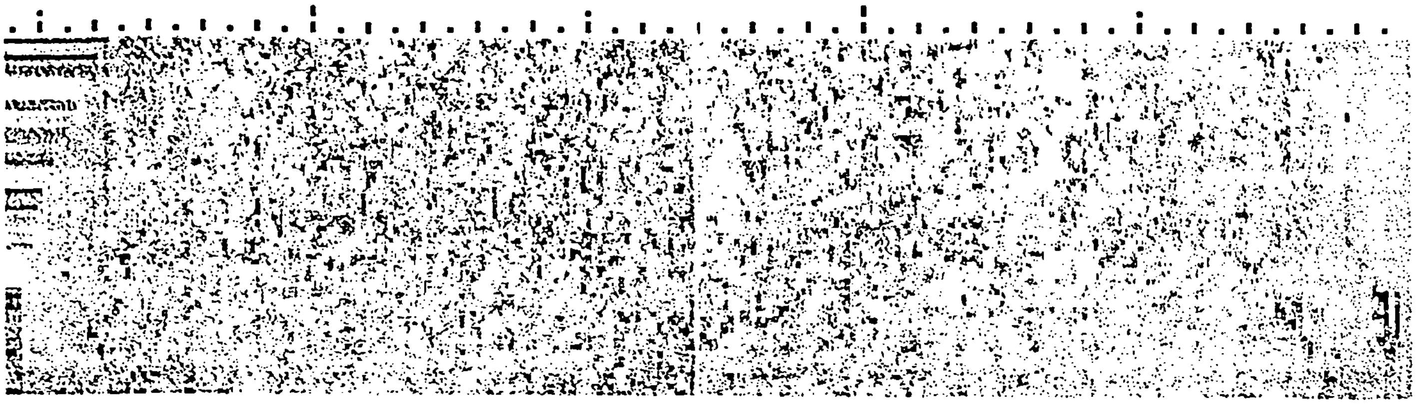

Fig. 4. A typical monochromatic, photometric scan of one-quarter of the Sun (measured in latitude) which will be used to detect large-scale heat-flow inhomogeneities.

3. PLANS FOR WORK DURING THE FINAL CONTRACT PHASE

General problems anticipated during the final six months of the contract in obtaining the goals discussed below are the absence of Dr. Chiang for three months while he is a Visiting Scientist at National Radio Astronomy Observatory and the possible absence of sunspots.

3.1 Influence of Faculae on Solar Irradiance

The work described in Section 2.1 fulfills the terms of the contract and no further work will be performed on this topic.

3.2 Model of the Influence of Sunspots on Solar Irradiance

Dr. Graham is nearing completion of a modification of the code described in Section 2.2 which will provide a realistic representation of heat flow in the presence of a sunspot. As before, this code will run on the Cromemco MC68000-based microcomputer. It is estimated that multi-CPU-day runs will be required to attain a convective steady state with this new model. It is planned for Dr. Graham to consult at AER during this final phase of the project and for Drs. Foukal, Chiang, and Graham to prepare a paper on the results obtained with the new model. The dynamical model will provide a more secure estimate of the effect of sunspots upon the luminosity of the Sun than provided by an eddy heat diffusion model (Foukal et al. (1983), Ap. J., 267, 863).

3.3 Observations of the Influence of Sunspots on Solar Irradiance

Further observations of sunspots to provide measured sunspot areas will be attempted by Dr. Foukal during the remaining six months of the contract. The success of this is contingent upon the presence of sunspots which, however, have been few in number during the past year.

The observations of sunspot bright rings described in Section 2.3 will be analyzed during the remaining six months of the contract using existing analysis programs at A.E.R.

3.4 Observations of Large-Scale Heat-Flow Inhomogeneities

Work to be completed during the final six months of the contract includes the extension of the procedures described in Section 2.4 to the data from the remaining 11 days, smoothing and co-adding of the scenes to reveal large-scale features, and, if necessary, statistical testing for giant convective cells. Priority is being given to this project during the time while Dr. Chiang is at A.E.R., before his visit at N.R.A.O. These results will be described in a paper to be prepared by Drs. Chiang, Foukal, and Petro.