CALCIUM PLAGE INTENSITY AND SOLAR IRRADIANCE VARIATIONS

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Abstract. We have established a statistical relation between the facular contribution to the solar irradiance and the intensity of the associated calcium plage. For the solar irradiance data the ACRIM measurements were used. The quiet-Sun level of the irradiance was determined as a function of the time for the period studied. A sample of plages in the period of the solar activity minimum was selected, during the periods when no spots were present on the solar disc. We have expressed the dependence studied through the parameter $C_p$ in the 'proxy' PFI concept. The parameter $C_p$ could be related to the plage intensity ($I$) as $C_p = 0.006I + 0.003$. The mean value of the parameter $C_p$ ranged between 0.015 and 0.017 depending on the choice of samples.

1. Introduction

The concept of the 'proxy' sunspot and facular contributions to the perturbations of the solar irradiance ($PSI$ and $PFI$, respectively) has been a very successful statistical approach in modelling the changes of solar irradiance on a time scale of weeks (Schatten et al., 1985; Lawrence et al., 1985; Foukal and Lean, 1986; Chapman, Herzog, and Lawrence, 1986; Chapman, 1987; Lawrence, 1987; Lawrence, Chapman, and Herzog, 1988; Willson and Hudson, 1988; Vrgnak, Ruždjak, and Ružić, 1990). Although very simple, it reproduces these changes fairly well in periods of high activity, as well as in periods of low activity when active regions appeared on the solar disc only occasionally. In simple situations with only one active region (AR) on the disc, the facular influence is directly evident in the wings of the irradiance dip profiles (Vrgnak, Ruždjak, and Ružić, 1990). When an AR is close to the limb, the facular irradiance perturbation becomes larger than the irradiance decrease caused by the sunspot group and results in an irradiance excess. A detailed study of such simple cases could eventually help in deciding between the hot-wall model and hillock model for facular emission (Schatten, Mayr, and Omidvar, 1987).

When the radiative energy balance of an AR is considered (Chapman, 1987; Vršnak, Ruždjak, and Ružić, 1990) the concept of $PFI$ becomes dubious since it does not include a dependence on the plage intensity. This can be especially important in statistical studies of the solar luminosity variations (Foukal and Lean, 1986; Lawrence, 1987; Chapman, Herzog, and Lawrence, 1988; Lawrence, Chapman, and Herzog, 1988) since faculae affect the solar irradiance over a much longer period than sunspots (Lawrence, 1987; Chapman, Herzog, and Lawrence, 1988; Vršnak, Ruždjak, and Ružić, 1990). Here, we will present a simple statistical study to relate the facular irradiance perturba-

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tion ($\Delta S$) to the plage intensity ($I$). The analysis is based on spaceborne measurements of $\Delta S$ in the period of the solar activity minimum of cycle 21. Simple activity patterns on the solar disc in this period offer a rather straightforward procedure with only a few assumptions used. An indication of such a relation could be found in sophisticated ground based photometric measurements (Lawrence et al., 1985; Lawrence, 1988; Lawrence, Chapman, and Herzog, 1988; Steinegger et al., 1991).

2. The Data Set

For the study, we used the ACRIM irradiance measurements in the period May 1984–December 1986. This is the period after the SMM satellite was stabilized, providing highly accurate irradiance measurements again (Willson and Hudson, 1988). The mean daily value of the solar irradiance is given in Solar Geophysical Data (No. 530/II). The standard error of the relative measurement was frequently as small as 0.001 % for a one orbit average (Solar Geophysical Data, 499/suppl.).

The facular influence on the irradiance, expressed in ppm (parts per million), can be written in the PFI concept as

$$PFI = C_p A_p f(\mu) = C_p A_p (\mu - 3\mu^2 + 2),$$

where $A_p$ is calcium plage area expressed in ppm of the solar hemisphere and $\mu$ is the normalized distance from the disc center; $\mu = \cos \phi \cos CMD$ ($\phi$ and CMD are the heliographic latitude and the central meridian distance, respectively). The parameter $C_p$ can be determined empirically and is usually assumed to be independent of plage intensity. It has a value between 0.01 and 0.02 (Lawrence, Chapman, and Herzog, 1988) and is commonly taken as $C_p = 0.0185$. Estimating the value of $\pm 0.05$ W m$^{-2}$ as an observational limit of the accuracy of the mean daily value of the irradiance, one finds that the plage area has to be about $A_p = 1000$ ppm of the solar hemisphere to produce an observable excess above this limit when the plage is close to the limb ($PFI$ has its maximum at $\mu = 0.17$, i.e., at $80^\circ$). In the period studied there were 133 days with no spots reported on the disc. In order to enrich the sample with brighter and larger plages we also took into account a wider sample with 36 days added, when only a small spot was reported close to the limb for which the irradiance perturbation was smaller than 0.01 W m$^{-2}$. The plage data (positions, areas and intensities) were taken from Solar Geophysical Data catalogues (Big Bear Observatory reports). The plage intensity is defined as the difference between the mean intensity of the plage elements and the local threshold ($6\%$ of the local background intensity) measured as a percentage of the background intensity of the quiet Sun at the disc center. The measured intensity excess is then multiplied by a factor 2 to maintain uniformity with the previous visual scale (used before October 1, 1982).

The positions and areas of eventual spots were checked in the Solar Geophysical Data and Solnechnye Dannye lists (the observations of spots listed in these catalogues are shifted by approximately $\frac{1}{2}$ day, which improves the coverage).

In Figure 1(a) we present the distribution of the plages in brightness intervals of 0.5.