TIME PROFILES OF SOLAR IRRADIANCE DIPS

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Abstract. ACRIM data have been analyzed to study the time profiles of simple irradiance dips caused by single active regions. Comparison of the average characteristics of the dips appearing in the minimum and maximum of the solar cycle shows that there are no significant differences. In both periods we disclosed the facular irradiance excess in the profile wings having typical duration of two to three days and an amplitude of about 20% of the dip amplitude. The profiles were asymmetric, with a stronger and longer excess in the trailing wing. We determined an 'average' profile which was attributed to an idealized active region, and we calculated the luminosity perturbation caused by it. Excess radiation in the wings of the profile compensates about \( \frac{1}{3} \) of the deficit in the dip. In the most simple case from our sample we compared the profile based on ACRIM measurements and the proxy profile estimated using sunspot and plage areas published in Solar Geophysical Data catalogues. The comparison indicates that the facular excess was compensating instantaneously about \( \frac{2}{3} \) of the luminosity deficit caused by sunspots.

1. Introduction

The relation between the radiative deficit caused by sunspots and the facular radiative excess is very intriguing, since it can provide a better insight into the nature and properties of sunspots and faculae and can disclose the role of the magnetic fields in the energy transport process (Wilson, 1971; Parker, 1974a, b; Chiang and Foukal, 1985; Schatten, Mayr, and Omidvar, 1987; Foukal, 1987; Vršnak and Ruždjak, 1988; Pap and Vršnak 1989). It is important to estimate whether the total radiative energy deficit caused by sunspots is balanced by the total facular radiative energy excess when an active region (further AR) is considered (Schatten et al., 1985; Lawrence et al., 1985; Chapman, Herzog, and Lawrence, 1986; Foukal and Lean, 1986; Lawrence, 1987; Lawrence, Chapman, and Herzog, 1988). Results of sophisticated ground based photometric measurements led Chapman, Herzog, and Lawrence (1986) and Lawrence, Chapman, and Herzog (1988) to the conclusion that the integrated facular radiative excess of an AR compensates between 70% and 120% of the deficit caused by sunspots. However, faculae compensate this energy on a considerably longer time-scale which means that the radiative power deficit and excess are not balanced.

The ground-based photometric measurement brought a new insight to the problem of the energy balance of an AR, but one should be aware of their limitations which are principally imposed by the Earths atmosphere, and the techniques of measurements used (Lawrence et al., 1985; Lawrence, Chapman, and Herzog, 1988). The measurements obtained by the ACRIM radiometer onboard SMM provided very precise


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bolometric data of the solar irradiance. However, in the data sets most frequently used, there were commonly several active regions present on the solar disc and the ACRIM discloses just an integral perturbation. The period close to the solar activity minimum which was not considered so often, offers much simpler situations since frequently there was only a single AR present on the solar disc. We shall analyze the observations of irradiance dips related to rather simple situations on the disc and compare them with the results provided by groundbased photometry. We will determine common properties of dip profiles associated with different ARs and estimate the total solar luminosity perturbation caused by an idealized active region. Also we will investigate possible differences between the properties of the profiles appearing in the period close to the solar activity minimum and the maximum.

The considered dips were caused by some of the largest sunspot groups in the analyzed periods. Specially, these ARs were characterized by an increased noise storm activity (Elgarøy, 1977) disclosing enhanced nonthermal processes (Benz and Zlobec, 1983; Stewart, Brueckner, and Dere, 1986). Such activity was absent or very weak during the disc passages of other large sunspot groups which did not affect the irradiance (Vršnak and Ruždjak, 1988, 1989).

2. Time Profiles

For the analysis we selected two periods (March–November 1980 and May 1984–June 1985), to embrace the solar irradiance dips in different phases of the solar activity cycle. These periods were characterized by a low level of noise in the ACRIM measurements (Willson and Hudson, 1988). Preliminary results concerning dip profiles which appeared in these periods are presented by Vršnak, Ruždjak, and Ružić (1988). First, we shall estimate an approximate behaviour of the unperturbed level of the solar irradiance, i.e. the level which should be observed in the considered periods if ARs were absent. We will call it the quiet-Sun level (QSL).

For the period October 1984–June 1985 (further: the period 1984–1985) we used the ACRIM measurements published in Solar Geophysical Data (further SGD) No. 515B. The values of the QSLs were determined when no sunspots were present at the solar disc and the plage area was minimal. Special care was taken on plage regions situated close to the solar limb, since the facular contribution is most important there (Lawrence et al., 1985). For the selected days in the period 1984–1985 we estimated the QSL (Table I) by substracting the 'proxy' values of the facular contribution from the measured irradiance (S). The proxy facular contribution can be represented in the form

\[
PFI = C_p A_p (\mu - 3\mu^2 + 2)
\]  
(1)

(Chapman, Herzog, and Lawrence, 1986), where \( A_p \) is the published AR plage area expressed in parts per million (further ppm) of the solar hemisphere. The dependence of the PFI on the position of an AR is given in the factor containing \( \mu \) which is related to the heliographic latitude (\( \beta \)) and central meridian distance (\( \lambda \)) as \( \mu = \cos \beta \cos \lambda \), while the values of the empirical coefficient \( C_p \) range from 0.01 to 0.02 according to different
Fig. 1. Solar irradiance variations in the studied periods. Simple dips are denoted by $s$, while complex dips are denoted by $c$. Thin lines represent the estimated QSLs in three periods. Note that the ordinate is stretched in the last two panels.

authors. Through this study we used the value $C_p = 0.0185$ (Chapman, Herzog, and Lawrence, 1986) since it provides a consistency of the proxy profile and the observed profile in the simples case from our sample (Section 4). On the other hand, the value of $C_p$ could be inferred from some general characteristics of the profiles. For example, the duration of the dip is related to the particular position of AR at which the sunspot and the facular contributions cancel. Taking for the average duration of the dip the values $T_0 = 8.5$ days (Table II) and for the average ratio of plage to sunspot area in an AR the value $A_p/A_s \approx 13 \pm 5$ (Lawrence, 1987) one obtains $C_p \approx 0.015$. However, estimation of $C_p$ from the observed profiles requires careful analysis and we leave it for a separate paper, where the evolution and the geometry of ARs will be considered.

We calculated the proxy facular contributions ($AS_{ppm}$) for the selected days in the period 1984–1985 using the values of $A_p$ published in SGD catalogues (Nos. 502A and 503A). The obtained corrections for QSL were negligible in all cases and we want to note that another choice of $C_p$ would not change the obtained values for QSL listed in Table I. A linear least-square fit through the points listed in Table I gives an expression for the QSL in the period 1984–1985:

$$QSL(t) = (1366.7 \pm 0.03) - (0.0017 \pm 0.0003)t,$$

where $t$ is the time expressed in days, starting on January 1, 1985.

The QSL during the dip of May 11, 1984 was determined considering the period after
the dip. As referent days we took May 25 and 26 which were characterized by minimum sunspot area, and minimum plage area close to the limb. Using Equation (1) and the expression for the proxy sunspot contribution,

$$PSI = C_s A_s \mu (3\mu + 2),$$

we approximately determined the irradiance perturbation ($\Delta S_{ppm}$) caused by facular regions and sunspots on both days. In Equation (3) $A_s$ represents the sunspot group area in ppm of the hemisphere and $C_s$ is the empirically determined coefficient $C_s = 0.164$ (Chapman, Herzog, and Lawrence, 1986). For the parameter $A_s$ we used the daily average of the values reported by different observations (SGD No. 479A). The spread of these values is the main source of the uncertainty of $\Delta S_{ppm}$ and so of $QSL$ (further we shall use the standard deviation as a measure of the spread of various quantities). Using Equations (1) and (3) we obtained values for $\Delta S_{ppm}$ as $-290 \pm 90$ and $-180 \pm 50$ on May 25 and 26. Since the measured irradiance ($S$) on these days was $1366.7$ and $1366.9$ W m$^{-2}$ we find for the values of $QSL$ $1367.10 \pm 0.1$ and $1367.15 \pm 0.06$ W m$^{-2}$ respectively. So, during the dip of May 11, 1984, we shall use the value $QSL'' = 1367.1 \pm 0.1$ W m$^{-2}$.

In order to derive the $QSL$ values in the 1980 period we chose two periods (14–17 March and 3–6 August 1980) when no prominent dips or peaks appeared in the solar irradiance measurements and which were also characterized by low solar activity. A special property of these two periods was the absence of broadband solar radio noise storms which are closely connected with the appearance of the solar irradiance variations (Vršnak and Ruždiak, 1988, 1989). We have calculated proxy facular and sunspot contributions to the solar irradiance for each day of these two periods (except for March 15 when sunspot data were lacking) using the values for $A_p$ and $A_s$ as reported in SGD catalogues (Nos. 429A and 434A). The daily values of $QSL$ were determined using the daily values of $S$ published by Willson (1984) and the calculated daily $\Delta S_{ppm}$. We estimated the average values of the $QSL$ in the two chosen periods as $1368.70 \pm 0.1$ and $1368.55 \pm 0.1$ (Table I).

### Table I

<table>
<thead>
<tr>
<th>Date</th>
<th>$t$ (days)</th>
<th>$S$ (W m$^{-2}$)</th>
<th>$\Delta S_{ppm}$</th>
<th>$QSL$ (W m$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14–17 Mar., 1980</td>
<td>+76</td>
<td>1368.80</td>
<td>+66</td>
<td>1368.70</td>
</tr>
<tr>
<td>25 May, 1984</td>
<td>-</td>
<td>1366.7</td>
<td>-290</td>
<td>1367.1</td>
</tr>
<tr>
<td>26 May, 1984</td>
<td>-</td>
<td>1366.9</td>
<td>-180</td>
<td>1367.1</td>
</tr>
<tr>
<td>27 Oct., 1984</td>
<td>-65</td>
<td>1366.8</td>
<td>0.0</td>
<td>1366.8</td>
</tr>
<tr>
<td>5 Mar., 1985</td>
<td>+63</td>
<td>1366.5</td>
<td>+0.7</td>
<td>1366.5</td>
</tr>
<tr>
<td>14 Apr., 1985</td>
<td>+103</td>
<td>1366.5</td>
<td>+11.0</td>
<td>1366.5</td>
</tr>
<tr>
<td>26 June, 1985</td>
<td>+176</td>
<td>1366.4</td>
<td>+2.8</td>
<td>1366.4</td>
</tr>
</tbody>
</table>
A linear least-square fit through all determined points $QSL(t)$ gives an approximation of the $QSL$:

$$QSL'' = (1368.8 \pm 0.09) - (0.0010 \pm 0.0005)t,$$

where $t$ is the time starting on January 1, 1980. Since the profiles obtained using Equations (2) and (4) show similar characteristics independent of $t$ (see Table II) we assume that the inclinations of $QSL'$ and $QSL''$ are accurate enough, and that the main uncertainty of $QSL$ is introduced in the first factors on the right hand sides of Equation (2) and (4). In the further analysis we will assume that the uncertainties of $QSL$ are 0.05, 0.1, and 0.1 for the periods 1984–1985, May 1984, and 1980, respectively.

Two different types of irradiance dips: 'simple' dips (denoted by 's' in Figure 1) and 'complex' dips (marked by 'c') could be distinguished (Vršnak, Ruždjak, and Ružič, 1988). The former are caused either by a single, large, and dominant sunspot group or by few sunspot groups which are situated at about the same heliographic longitude, so that the profiles are similar in duration (Table II). The second type of profiles is caused by large complexes of activity, containing several sunspot groups which are dispersed sometimes up to 90° in longitude, thus causing composite dip profiles lasting up to 20 days. We will concentrate here on the four simple dips in 1980 and five simple dips in 1984–1985 (marked by 's' in Figure 1). Estimates of the dip amplitudes ($\Delta S$) are given in Table II together with the estimates of their durations ($T_0$). The uncertainty in $\Delta S$ in 1980 and May 1984 is $\pm 0.1$ W m$^{-2}$ and it is determined by the uncertainty of $QSL$, while in the period 1984–1985 it is $\pm 0.05$ W m$^{-2}$ due to the presented precision of irradiance data published in SGD (No. 515B). The average properties of the dips

<table>
<thead>
<tr>
<th>Dip min.</th>
<th>$\Delta S$ (W m$^{-2}$)</th>
<th>$T_0$ (days)</th>
<th>$T_p/T_0$</th>
<th>$T_i/T_0$</th>
<th>$\Delta S_p/\Delta S$</th>
<th>$\Delta S_i/\Delta S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 May, 1980</td>
<td>1.01</td>
<td>8.4</td>
<td>0.20</td>
<td>0.50</td>
<td>0.05</td>
<td>0.40</td>
</tr>
<tr>
<td>23 Sept., 1980</td>
<td>0.83</td>
<td>7.5</td>
<td>0.15</td>
<td>0.20</td>
<td>0.10</td>
<td>0.15</td>
</tr>
<tr>
<td>13 Oct., 1980</td>
<td>1.40</td>
<td>7.6</td>
<td>0.40</td>
<td>0.35</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>22 Oct., 1980</td>
<td>1.22</td>
<td>10.0</td>
<td>0.25</td>
<td>–</td>
<td>0.30</td>
<td>–</td>
</tr>
<tr>
<td>Average</td>
<td>1.1</td>
<td>8.4</td>
<td>0.25</td>
<td>0.35</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>$\pm 0.3$</td>
<td>$\pm 1.1$</td>
<td>$\pm 0.10$</td>
<td>$\pm 0.15$</td>
<td>$\pm 0.10$</td>
<td>$\pm 0.10$</td>
</tr>
<tr>
<td>11 May, 1984</td>
<td>1.50</td>
<td>10.0</td>
<td>0.00</td>
<td>0.55</td>
<td>0.00</td>
<td>0.20</td>
</tr>
<tr>
<td>25 Nov., 1984</td>
<td>0.45</td>
<td>9.7</td>
<td>0.45</td>
<td>0.20</td>
<td>0.45</td>
<td>0.40</td>
</tr>
<tr>
<td>21 Jan., 1985</td>
<td>0.45</td>
<td>5.5</td>
<td>–</td>
<td>0.30</td>
<td>–</td>
<td>0.20</td>
</tr>
<tr>
<td>25 Apr., 1985</td>
<td>0.70</td>
<td>9.2</td>
<td>0.20</td>
<td>0.50</td>
<td>0.15</td>
<td>0.30</td>
</tr>
<tr>
<td>13 May, 1985</td>
<td>0.50</td>
<td>9.2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Average</td>
<td>0.7</td>
<td>8.7</td>
<td>0.20</td>
<td>0.40</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>$\pm 0.4$</td>
<td>$\pm 1.8$</td>
<td>$\pm 0.20$</td>
<td>$\pm 0.15$</td>
<td>$\pm 0.20$</td>
<td>$\pm 0.10$</td>
</tr>
<tr>
<td>Average all</td>
<td>0.9</td>
<td>8.5</td>
<td>0.25</td>
<td>0.40</td>
<td>0.15</td>
<td>0.30</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>$\pm 0.4$</td>
<td>$\pm 1.5$</td>
<td>$\pm 0.15$</td>
<td>$\pm 0.15$</td>
<td>$\pm 0.15$</td>
<td>$\pm 0.10$</td>
</tr>
</tbody>
</table>
(presented in Table II together with standard deviations) were similar in 1980 and 1984–1985.

A considerable irradiance excess can be noted at the preceding and/or following wings of the dips. It can be detected in 14 out of 18 studied wings. Such time profiles resemble the composite profiles obtained by groundbased photometric measurements (Lawrence et al., 1985). The average duration of the excess in the wings was about 2.5 days and the average amplitude was about 20% of the dip amplitude. The preceding wing excess ($T_p/T_0 = 25 \pm 15\%$) was in principle shorter than the trailing wing ($T_t/T_0 = 40 \pm 15\%$) and its average amplitude ($\Delta S_p/\Delta S = 15 \pm 10\%$) was smaller than that of the trailing wing ($\Delta S_t/\Delta S = 30 \pm 10\%$).

The decrease of the solar irradiance at a particular moment ($t$) is presented as a function of the time difference $T = t - t_0$, $t_0$ being the moment of the dip minimum. The value of the decrease $\Delta S(T)$, normalized with respect to the dip amplitude is denoted as $f(T)$, and can be expressed as

$$f(T) = \frac{\Delta S(T)}{\Delta S} = \frac{(S(T) - S_0)}{(S_0 - S(0))}.$$  

(5)

---

**Fig. 2.** Superposition of the normalized profiles $f(T)$, obtained by overlapping their minima. The sixth-order polynomial fit is presented: (a) 1980 period; (b) 1984–1985 period; (c) the combined 1980–1984/85 profile. The uncertainty in QSL is illustrated by error bars.
Here $\Delta S(T)$ is the value of the solar irradiance at the moment $T$; $S_0$ is the estimated QSL value of the irradiance during the dip, $S(0)$ is the solar irradiance in the minimum of the dip ($T = 0$), and $\Delta S$ is the amplitude of the dip ($\Delta S = S_0 - S(0)$).

The results for all studied dips, given separately for the two analyzed periods are presented in Figure 2 together with the sixth-order polynomial fit. The selected solar irradiance dips in the period May 1984–June 1985 were fairly well isolated one from another and, hence, their profiles were not interfering. This was not the case in the solar maximum period, where the wings of the profiles were often overlapping with others, deforming the real profiles, and also causing additional uncertainties in the estimate of the QSL. In Figure 3 we present the symmetrized profiles ($-T \rightarrow T$) which were obtained by fitting the sixth-order polynomial fit.

![Figure 3. Superposition of symmetrized, normalized profiles $f(T)$. The sixth-order polynomial fit is presented for: (a) 1980 period; (b) 1984–1985 period; (c) the combined 1980–1984/85 profile.](image)

The 'average dip' duration of the analyzed profiles in the 1984–1985 period as estimated from the fitted profile was $T'_0 = 9.4$ days, while the irradiance excess in the profile wings had a duration about three days. Figure 2 discloses an asymmetry between the preceding and the trailing wing. The preceding wing excess in average lasted for 30% of the dip duration and had an amplitude of about 25% of the dip amplitude, while the
trailing wing excess lasted for about 40% of the dip duration with an amplitude of 35% of the dip amplitude. The accuracy is limited by the uncertainty of QSL and amounts to about ±10% for \( \Delta S_w/\Delta S \) and ±1 day for \( T_w \) and \( T_0 \) (Figure 2).

The fitted profile for the 1980 period is presented in Figure 2(a) while the fitted symmetrized profile is presented in Figure 3(a). We used the QSL as given by Equation (4) and neglected the perturbations caused by smaller ARs. The basic properties of the fitted profile are similar to those in 1984–1985 (Table III). The average duration of the dip was 8.8 days. The average durations of the preceding and trailing wings were 35% and 40%, while their amplitudes were 30% and 40%, respectively.

<table>
<thead>
<tr>
<th>Year</th>
<th>( T_0 )</th>
<th>( T_p/T_0 )</th>
<th>( T_f/T_0 )</th>
<th>( \Delta S_p/\Delta S )</th>
<th>( \Delta S_f/\Delta S )</th>
<th>( T_0'' )</th>
<th>( T_w''/T_0'' )</th>
<th>( \Delta S_w''/\Delta S'' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>9.4</td>
<td>0.30</td>
<td>0.40</td>
<td>0.25</td>
<td>0.35</td>
<td>8.3</td>
<td>3.3</td>
<td>0.17</td>
</tr>
<tr>
<td>1984–1985</td>
<td>8.8</td>
<td>0.35</td>
<td>0.40</td>
<td>0.30</td>
<td>0.40</td>
<td>9.1</td>
<td>4.0</td>
<td>0.10</td>
</tr>
<tr>
<td>All</td>
<td>9.0</td>
<td>0.30</td>
<td>0.40</td>
<td>0.30</td>
<td>0.40</td>
<td>8.7</td>
<td>3.6</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The results obtained from the fitted profiles presented in Figures 2 and 3 are given in Table III. By \( T_0', T_p', \) and \( T_f' \) we denoted the duration of the dip, the preceding wing and the trailing wing, while the amplitudes are denoted by \( \Delta S', \Delta S_p' \) and \( \Delta S_f' \), respectively. The duration of the dip as estimated from the symmetrized profile is denoted as \( T_0'' \), while \( T_w'' = T_{w'} - T_0''/2 \), where \( T_{w'} \) is the time of the wing excess maximum. Amplitudes of dips and wing excesses are denoted as \( \Delta S'' \) and \( \Delta S_w'' \).

The disclosed asymmetry of an ‘average’ profile can be explained in terms of a typical AR morphology and evolution. The asymmetry of profiles can be a result of the asymmetry of ARs, since faculae tend to be more common on the trailing part. Furthermore, sunspot groups develop on a time-scale comparable to the solar rotation rate, while the facular contribution becomes more important as the active region grows older (Lawrence, 1987). So, statistically it should be expected that the irradiance excess at the trailing wing of an ‘average profile’ is larger than on the preceding one.

3. An Estimate of the Luminosity Decrease

The obtained characteristic of an ‘average’ simple dip profile enables an estimate of the solar luminosity variation caused by an idealized active region (further IAR) which is virtually situated at the equator and is related to the ‘average’ dip profile. We will assume that the angular irradiance pattern related to IAR is constant, only corotating with the Sun. In this way the angular dependence of the irradiance pattern can be related to the observed time dependence. Furthermore, we shall assume that the amplitude of the dip does not change, since when a sample of several dips is averaged, one can expect that
there was about the same number of active regions characterized by increasing and
decreasing sunspot area determining the amplitude $\Delta S$ of an irradiance dip (Chapman,
Herzog, and Lawrence, 1986). As we shall consider only those dips caused by one
dominant AR and not by large complexes of activity, we shall neglect the effect of the
active region dimensions. This effect becomes important when extended active regions
characterized by $\Delta \lambda/360^\circ > \frac{1}{27}$ ($\Delta \lambda$ being the extension of AR) aproach the limbo and this
will be treated in a separate paper.

In order to estimate the variation of the solar luminosity, caused by the IAR which
is related to the ‘average dip’, we will define a spherical coordinate system with the origin
in the center of the Sun, and with the $z$-axis passing through the centre of the IAR. The
luminosity defect can be expressed in terms of the irradiance perturbation as

$$
\Delta L = \int_0^{\frac{\pi}{2}} \int_0^{2\pi} \Delta S(\theta, \phi) r \sin \theta \, d\phi \, d\theta,
$$

(6)

where $\Delta S(\theta, \phi)$ is the irradiance perturbation presented as a function of the angular
coordinates $\theta$ and $\phi$ (azimuthal coordinate) in this spherical coordinate system, while $r$
is the Earth-Sun distance. Furthermore, it will be assumed that the irradiance perturbation
is symmetric with respect to the $z$-axis and so is independent on $\phi$. Taking into
account the synodic rotation rate of $P \approx 27$ days, one can express the relation between
$\theta$ and the time $T$ as $\theta/2\pi = T/27$, which makes possible the transformation of the
observed (symmetrized) profile $F(T)$ to the profile $f(\theta) = \Delta S(\theta)/\Delta S$. We will approximate
the fitted profile $F(T)$ by the triangular symmetrized profile characterized by the
parametrs $T_0$, $T_w$ and $\Delta S_w/\Delta S$, which is accurate enough, since the errors introduced
by this approximation are smaller than the observational uncertainties of the profile
characteristics.

Using $\theta_0 = 2\pi T_0/27$ and $\theta_w = 2\pi T_w/27$ for $\theta_w < \pi/2$ and integrating (6), one obtains
$\Delta L = 2\pi r^2 \Delta S I$, where

$$
I = 1 - \frac{\sin \theta_0}{\theta_0} + \frac{2\Delta S_w}{\Delta S(\theta_w - \theta_0)} \left[ \sin \theta_0 + \sin \theta_w - 2 \sin \left( \frac{\theta_w + \theta_0}{2} \right) \right].
$$

(7)

Here the factor $1 - \sin \theta_0/\theta_0$ is related to the radiation deficit in the dip and the rest
represents the radiative excess in the wings. Taking the average characteristics of the
profiles $T_0 = 8.5$ days, $T_w = 2.5$ days and $\Delta S_w/\Delta S = 0.2$ (Table II) one obtains $I \approx 0.1$,
where the excess in the wings compensates about $\frac{1}{3}$ of the deficit in the dip. Taking a
typical amplitude of the dips as $\Delta S \approx 1$ W m$^{-2}$ (Table II) one obtains the luminosity deficits $\Delta L = 1.4 \times 10^{22}$ W. We applied the same procedure to all individual dips where
both wing excesses were observed (Table II) taking the mean values of the characteristics of the leading and trailing wing of the profile. In this way we obtained that in
average $33 \pm 15\%$ of the radiation deficit in the dip was compensated by the excess in the wings.
4. The Dip of April 25, 1985

We will discuss the limitations of our study considering the dip at the end of April, 1985, with minimum at April 25, 1985, which was the least interfered dip from our sample. It was caused by the AR complex NOAA/USAF 4647/4646 which crossed the central meridian on April 26, 1985.

![Graphs showing the dip profile and proxy dip based on published data.](image)

Fig. 4. (a) The recorded profile of the 25 April, 1985 irradiance dip with the sixth-order polynomial fit is presented. (b) Constructed, ‘proxy’ irradiance dip based on the published data on sunspot and plage areas (Solar Geophysical Data).

The fitted profile of the dip is presented in Figure 4. The facular influence on the daily value of the solar irradiance could be measured from April 19, when the preceding part of the plage area appeared at the east limb. The irradiance excess on the preceding wing ended on April 21, i.e., four days before the minimum of the dip and five days before the active region had crossed the central meridian. The values of irradiance were below the estimated QSL (Equation 2) till April 30, when the trailing wing excess started. The trailing part of the plage passed behind the solar limb on May 2, while on May 1, the preceding part of the plage of the AR complex NOAA/USAF 4650/4649 appeared on the east limb. This means that the facular contribution in the profile should be considered without applying corrections only till April 30 (Figure 4). The corrections were obtained using of the ‘proxy’ estimate for facular contribution given in Equation (1) where the areas $A_p$ and the positions of plages are interpolated values based on observations referred in SGD No. 503A; assuming that the coefficient $C_p$ does not depend on the properties of the particular active region one receives:

$$PFI_1/PFI_2 = (A_{p_1}/A_{p_2}) (\mu_1 - 3\mu_1^2 + 2)/(\mu_2 - 3\mu_2^2 + 2),$$

where $A_{p_1}$ and $A_{p_2}$ are the areas of plages of the ARS NOAA/USAF 4647/4646 and NOAA/USAF 4650/4649, respectively. This gives the relative contribution to the wing excess on May 1 as $PFI_1/PFI_2 = 3.6$ and on May 2, as $PFI_1/PFI_2 = 1.5$, providing the corrected values $\Delta S_{corr} = 0.8\Delta S_{obs}$ and $\Delta S_{corr} = 0.6\Delta S_{obs}$ for May 1 and 2, respectively. The perturbation of the solar irradiance caused by sunspots was negligible due to their extreme limb position. So, the contributions to the irradiance excesses on May 1
and May 2, can be estimated to $\Delta S_1 = 0.16 \, W \, m^{-2}$ and $\Delta S_2 = 0.12 \, W \, m^{-2}$. In Figure 4 we presented the corrected values of $\Delta S$ on May 1 and May 2.

Using the characteristic of the symmetrized profile for the April 25, 1985 dip ($T_0 = 9$ days, $T_w = 3$ days, $\Delta S_w / \Delta S = 0.2$) and $\Delta S = 0.7 \, W \, m^{-2}$, Equation (7) gives an estimate of the luminosity deficit as $(1.2 \pm 0.6) \times 10^{22} \, W$ where an uncertainty in $\Delta S$ of $\pm 0.05 \, W \, m^{-2}$ was taken into account (Section 2). The ratio of the excess contained in the wings and the luminosity deficit contained in the dip was $0.3 \pm 0.2$. The characteristics of the profile estimated by means of Equations (1) and (3) and using the published sunspot (SGD 490A) and plage (SGD 503A) areas (Figure 4(b)) gives (Equation 7) a net luminosity deficit about $1.2 \times 10^{22} \, W$, where the ratio of the excess in the wings and the deficit in the dip appears as 0.35, i.e., comparable to the ratio obtained directly from the ACRIM profile. The uncertainty of the profile is determined mainly by the spread of the values of $A_s$ close to the dip center and by the uncertainty of $C_p$ in the wings. For the values of $C_p$ ranging between 0.01 and 0.02, $\Delta L$ ranges between $1.2$ and $1.5 \times 10^{22} \, W$, but due to the uncertainty of $A_s$ values, the $\Delta L$ should be taken with uncertainty of $\pm 0.5 \times 10^{22} \, W$. Here the estimated ‘proxy’ luminosity perturbation caused by sunspots was $\Delta L_s = (3 \pm 0.5) \times 10^{22} \, W$, while the facular excess was ranging between $\Delta L_f = 1 \times 10^{22} \, W$ and $2 \times 10^{22} \, W$ for $C_p$ values between 0.01 and 0.02. Taking the value $C_p = 0.0185$ one finds that $\Delta L_f / \Delta L_s = \frac{2}{3}$ which is consistent with the estimate given by Lawrence (1987) ($\Delta L_f / \Delta L_s = 0.015 A_p / 0.16 A_s$), since in our case $A_s = 800 \pm 100 \, ppm$ of the hemisphere and $A_p = 6000 \pm 300 \, ppm$ (measured between $\pm 3$ days from central meridian passage). Taking the area of the sunspot group $A_s = 800 \, ppm$ of the hemisphere, one receives the average power deficit per unit area of the sunspot group $\Delta L_s / A_s = (1.2 \pm 0.2) \times 10^7 \, W \, m^{-2}$. Similarly, using $A_p = 6000 \pm 300 \, ppm$ of the hemisphere, one receives the average facular emission excess per unit area $\Delta L_f / A_p$ between $0.6 \times 10^6$ and $1.1 \times 10^6 \, W \, m^{-2}$ depending on the choice of $C_p$. This values are consistent with the values presented by Lawrence (1987) who estimated $\Delta L_s / A_s = (1 \pm 0.05) \times 10^7 \, W \, m^{-2}$ and $\Delta L_f / A_p = (0.9 \pm 0.1) \times 10^6 \, W \, m^{-2}$.

5. Conclusion

The analysis of the solar irradiance variations close to the solar activity maximum and minimum, reveals that the profiles of simple dips were similar in both periods, with a duration in average of about 8.5 days. However, the amplitude is larger in the maximum due to larger active region areas. Typically, one finds profiles two times deeper in the solar activity maximum than in the minimum. An estimate of the luminosity deficit for simple dips, under the assumption of a symmetrical irradiance angular pattern, gives values up to several times $10^{22} \, W$.

Our study reveals a measurable facular excess in the wings of the profiles in 14 out of 18 analyzed wings. The average duration of the facular excess in one wing was about 2.5 days or 30% of the dip duration. The average amplitude of the excess was about 0.1 W m\(^{-2}\), or about 20% of the dip amplitude. The observations in the studied periods

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indicate possible asymmetry of the dip profile but we want to stress that the number of considered cases was not sufficient to provide a reliable conclusion. The excess in the preceding wing was in average shorter and weaker than in the trailing wing (the average durations were 25% and 40% of the dip duration, respectively, while the average amplitudes of the excess in the wings were 15% and 30% of the dip amplitude, respectively).

In the case of the April 25, 1988 dip where interferences could be neglected, the observed profile was compared with the one constructed from the sunspot and facular areas using empirical ‘proxy’ estimates. So, we received the value of $2 \times 10^{22}$ W for the facular luminosity excess and $3 \times 20^{22}$ W for the luminosity deficit caused by sunspots, implying that about two thirds of the deficit was compensated by the facular excess. Comparing these values with the sunspot and facular areas one finds that the radiative power from sunspots (averaged over the sunspot area) was decreased by $10^7$ W m$^{-2}$, while the average facular emission excess was $10^6$ W m$^{-2}$.

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