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SOLAR ACTIVITY INFLUENCE ON EQUIVALENT WIDTHS OF SOME PHOTOSPHERIC LINES

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SUMMARY: Changes of equivalent widths for ten selected spectral lines (530.74 nm $\leq \lambda \leq$ 568.82 nm) were evaluated according to "Belgrade Program for Monitoring of Activity-Sensitive Spectral Lines of the Sun as a Star". Observations from August 1987 till May 1990 have been processed in the way for the first time presented here.

1. INTRODUCTION

After the successful experience with the full disk monitoring of some spectral lines as activity indexes for the Sun as a star and for other cool stars (Wilson, 1978; Belvedere et al, 1982; Livingston and Holweger, 1982; Rodono, 1983 etc...), the spectrophotometry of the integrated disk has been encouraged as a common observational approach for solar and stellar activity (Vukićević-Karabin and Arsenijević, 1986).

At the innovated solar spectrograph of the Belgrade Astronomical Observatory (Arsenijević et al, 1988) the long term monitoring program for 30 selected spectral lines according to certain criteria has been established (Arsenijević et al, 1987, Vince et al, 1988). So-called "Belgrade Program for Monitoring of Activity-Sensitive Spectral Lines of the Sun as a Star" started in August 1987 and is still going on.

Some preliminary results for the rising phase of the 22nd solar activity sycle (August 1987 – May 1990) were published recently (Karabin et al, 1990). For the same time interval, we present here detailed analysis about changes of equivalent widths for ten selected photospheric lines together with improved data processing and systematic errors elimination.

2. METHODS OF DATA PROCESSING

The data for ten photospheric spectral lines (530.74nm $\leq \lambda \leq$ 568.82nm) selected for studying possible changes with the solar activity are given in Tab. 1. Evaluation of equivalent widths was done by an especially for this purpose developed interactive software with possibility of selection the continuum level, normalization of a profile and numerical integration of the area limited by the contour of a spectral line.

Typical line profiles (FeI 530.74nm) before and after the equivalent width measuring procedure mentioned above is presented in Fig. 1. Equivalent width is indicated by the hatched area (1^b). All selected spectral lines in our program have clearly defined wings and local continuum, almost without blending effects (that was one of the reasons for them to be chosen). All measured equivalent widths are given in Tab. 2. Time is marked by t in Julian months (30.4375 days) since January 1, 1987, JD 2446797.

Even a brief look at the values in Tab. 2 assure us that all equivalent widths are subjected to systematyc errors (for example, all the values for May 12, 1989 are generally higher comparing to August 18, 1987). Our first task was to bring all measurements to the same conditions.

Table 1

Wavelengths of Spectral Lines (in nm)

Line	Element	Length
λ_1	FeI	530.74
λ_2	TiII	533.68
λ_3	MnI	539.47
λ_4	FeI	539.83
λ_5	FeII	542.53
λ_6	FeI	550.68
λ_7	ScII	552.68
λ_8	FeI	557.61
λ_9	CaI	560.13
λ_{10}	NaI	568.82

If we put on the abscissa equivalent widths of all lines for one date $t^{(i)}$ and on the ordinate the values of equivalent widths for another date $t^{(j)}$ we will get a diagram as in Fig. 2. On the assumption that there are no real changes of equivalent widths during the time interval $\Delta t = t^{(j)} - t^{(i)}$, a line which was drown through given points represents a certain *law of transformation*. If we assume this relation to be linear, we can write:

$$W^{(j)} = a^{(i,j)} W^{(i)} + b^{(i,j)}, \quad (1)$$

in which the coefficients $a^{(i,j)}$ and $b^{(i,j)}$ were determined by the method of least squares. Double index (i,j) designates the transfer from the date $t^{(i)}$ to the date $t^{(j)}$.

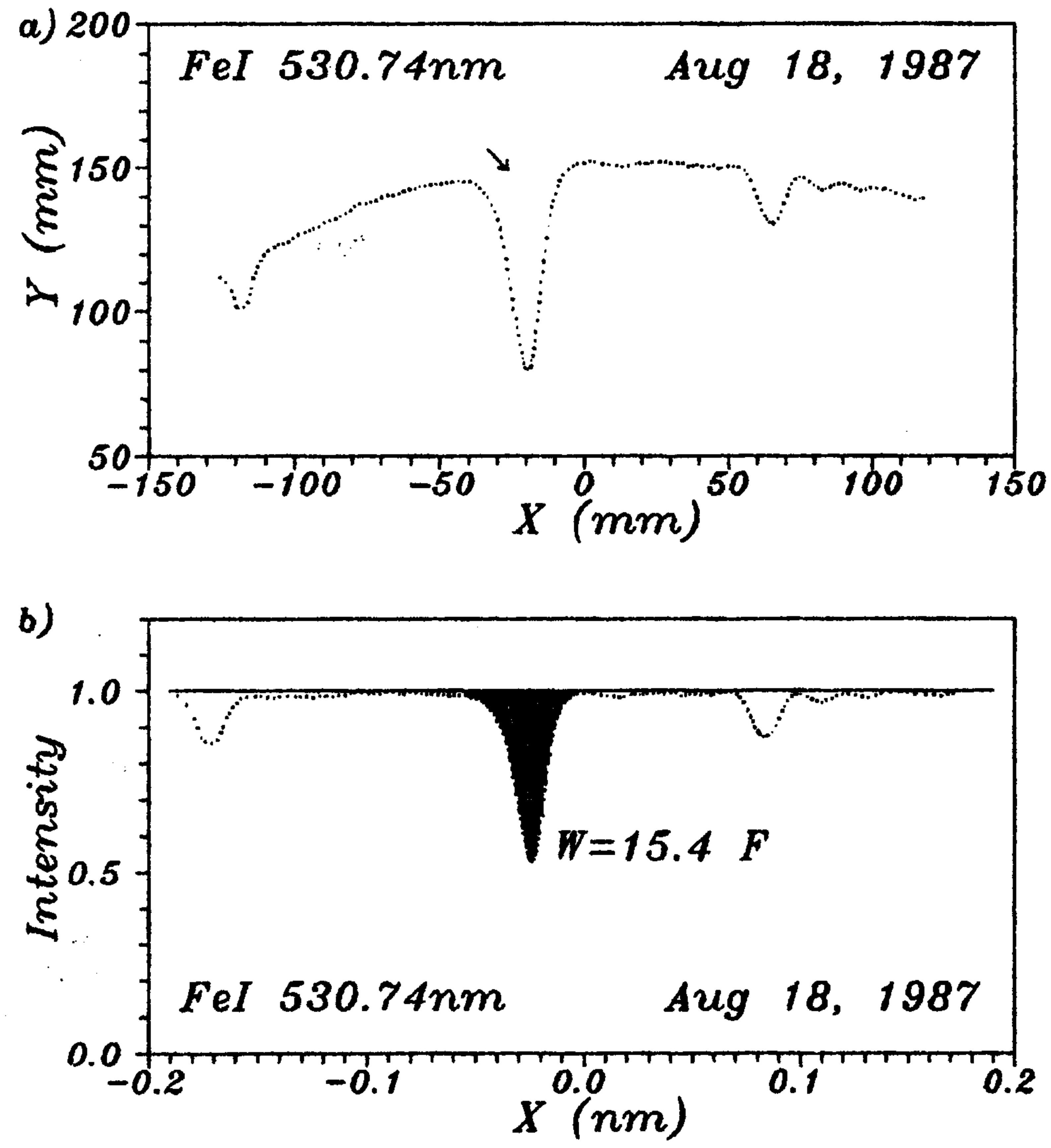

Fig. 1. The line profile of FeI 530.74 nm before (a) and after (b) the evaluation. The area corresponding to the equivalent width is hatched.

Table 2

Measured Values of Equivalent Widths (in Fraunhofers)

Date	t	Equivalent widths									
		FeI λ_1	TiII λ_2	MnI λ_3	FeI λ_4	FeII λ_5	FeI λ_6	ScII λ_7	FeI λ_8	CaI λ_9	NaI λ_{10}
Aug 18, 1987	7.5	15.4	11.1	12.7	11.7	6.5	20.3	13.0	19.1	17.8	15.6
May 10, 1988	16.3	15.3	11.6	12.2	11.9	6.7	19.1	12.5	19.0	17.8	17.9
Jul 11, 1988	18.3	15.0	10.7	12.9	11.7	6.6	18.5	12.1	17.7	18.0	17.5
Sep 5, 1988	20.1	15.4	12.0	13.0	13.1	7.4	20.9	13.5	19.6	20.7	19.2
May 12, 1989	28.3	16.1	12.2	12.4	13.4	7.1	21.1	13.4	20.8	20.7	21.5
Jul 24, 1989	30.7	13.3	10.5	11.0	11.2	6.7	18.4	11.9	16.8	18.7	16.5
Oct 24, 1989	33.7	13.8	10.6	11.4	10.8	6.3	18.0	11.2	16.5	17.0	17.1
May 4, 1990	40.0	14.7	12.8	11.0	11.2	6.6	18.5	11.3	17.4	18.8	18.3

However, if spectral lines show real change of equivalent width with time, transformation (1) should be written as:

$$W^{(i,j)} = a^{(i,j)}W^{(i)} + b^{(i,j)}, \qquad (2)$$

where $W^{(i,j)}$ have to be taken as equivalent width measured on $t^{(i)}$, but transfered to the system $t^{(j)}$. We suppose that the difference between $W^{(j)}$ and $W^{(i,j)}$ comes from the solar activity.

It is obvious that the coefficients $a^{(i,j)}$ and $b^{(i,j)}$ have to be determined using the spectral lines which *do not change* with the activity. That is the condition for applying transformation (1). However, by using all ten spectral lines (Fig. 2), only points representing the lines which do change their equivalent widths with the activity, would not lie down the straight line. With the exeption of λ_{10} (NaI 568.82nm), all other deviations are rather small because of the short time interval.

In order to find the spectral lines which change equivalent widths with the activity we need the coefficients for the transformations (2). But for that we have to know spectral lines which do not change with time. Solution is in the method of succesive approximations.

The aim is to reduce all measurements to date $t^{(1)}$ which is August 18,1987. If we know the coefficients for transfer from $t^{(1)}$ to any other date $t^{(j)}$, the reduction of all measurements to $t^{(1)}$ will be achieved by inversion of transformation (2):

$$W^{(j,1)} = \frac{W^{(j)} - b^{(1,j)}}{a^{(1,j)}}. \qquad (3)$$

In the first pass, all ten lines have been used for determination of the coefficients $a^{(1,j)}$ and $b^{(1,j)}$. We got seven diagrams similar to that as on Fig. 2 (abscissa always being $t^{(1)}$). For each equivalent width and each date the relation (3) was applied. In such a way those lines with equivalent widths remaining in the $\pm\sigma$ error limit are used in second pass, for better determination of the coefficients $a^{(1,j)}$ and $b^{(1,j)}$. Procedure should be repeted till the results would reach the accordance.

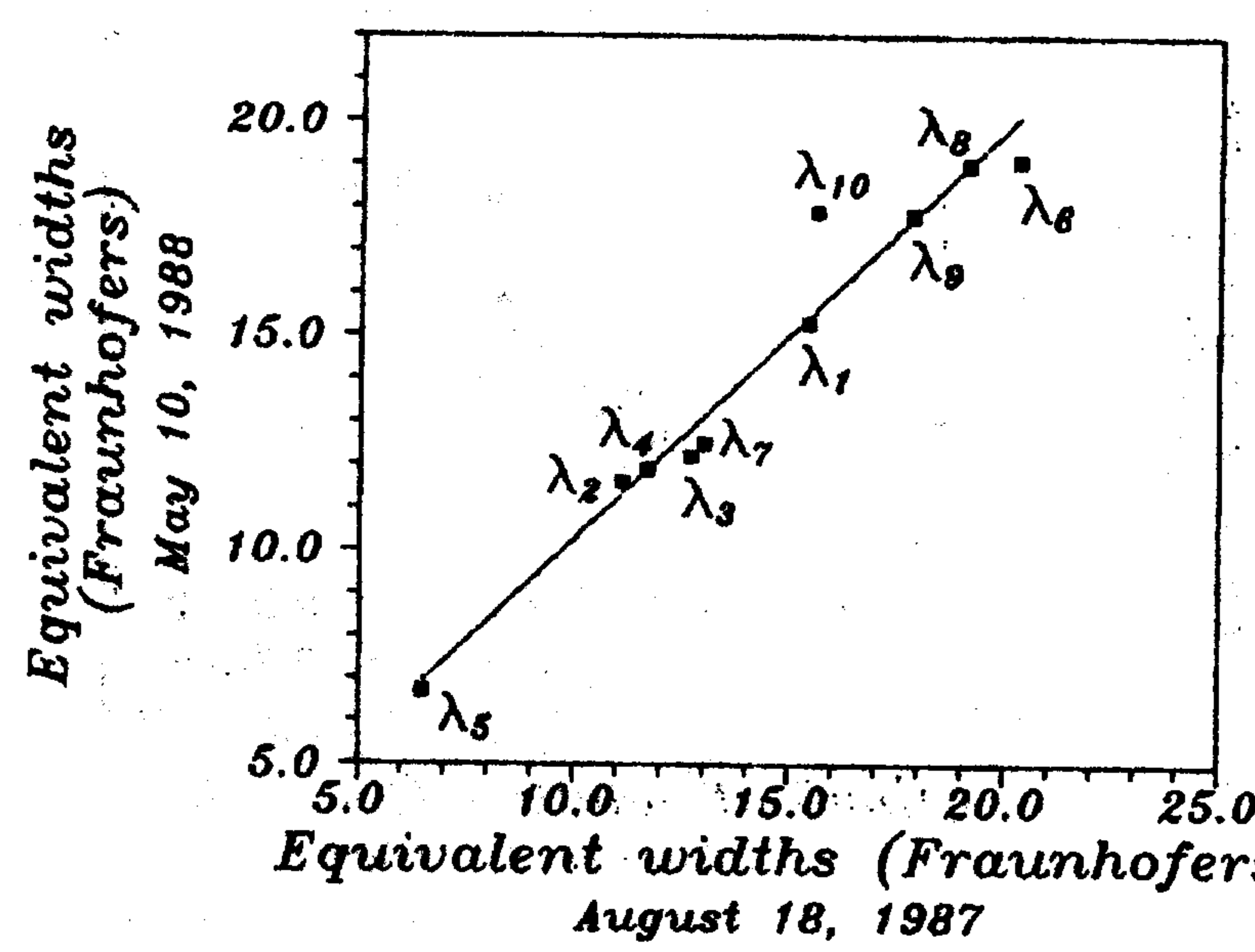

Fig. 2. **Determination of the coefficients $a^{(i,j)}$ and $b^{(i,j)}$.**

Table 3
Reduced Values of Equivalent Widths
(W, in Fraunhofers)

Date	t	Eqivalent widths									
		FeI λ_1	TiII λ_2	MnI λ_3	FeI λ_4	FeII λ_5	FeI λ_6	ScII λ_7	FeI λ_8	CaI λ_9	NaI λ_{10}
Aug 18, 1987	7.5	15.4	11.1	12.7	11.7	6.5	20.3	13.0	19.1	17.8	15.6
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May 4, 1990	40.0	15.8	13.6	11.5	11.7	6.4	20.2	11.8	18.9	20.6	20.0

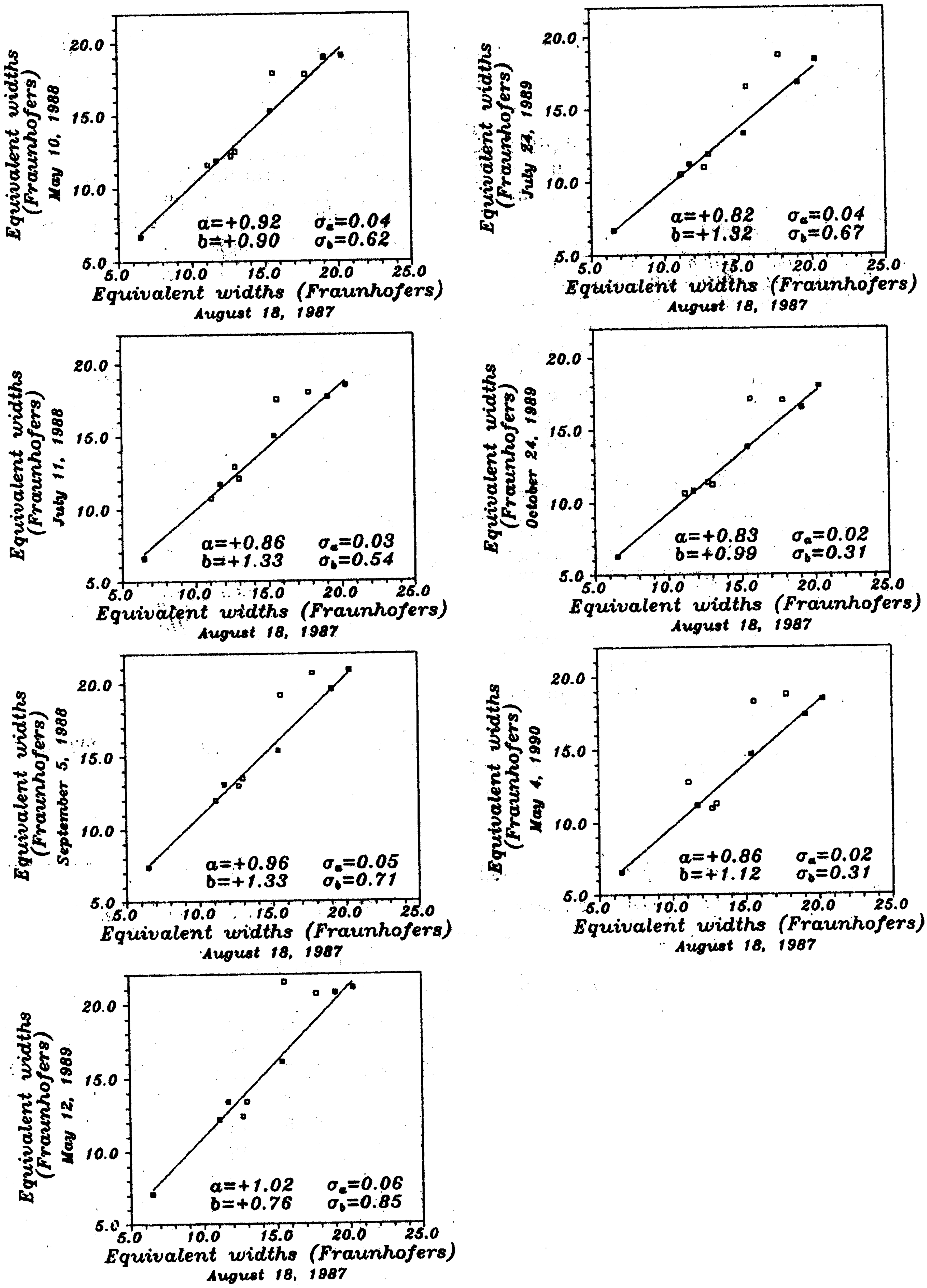

Fig. 3. Final values of the coefficients $a^{(1,j)}$ and $b^{(1,j)}$.

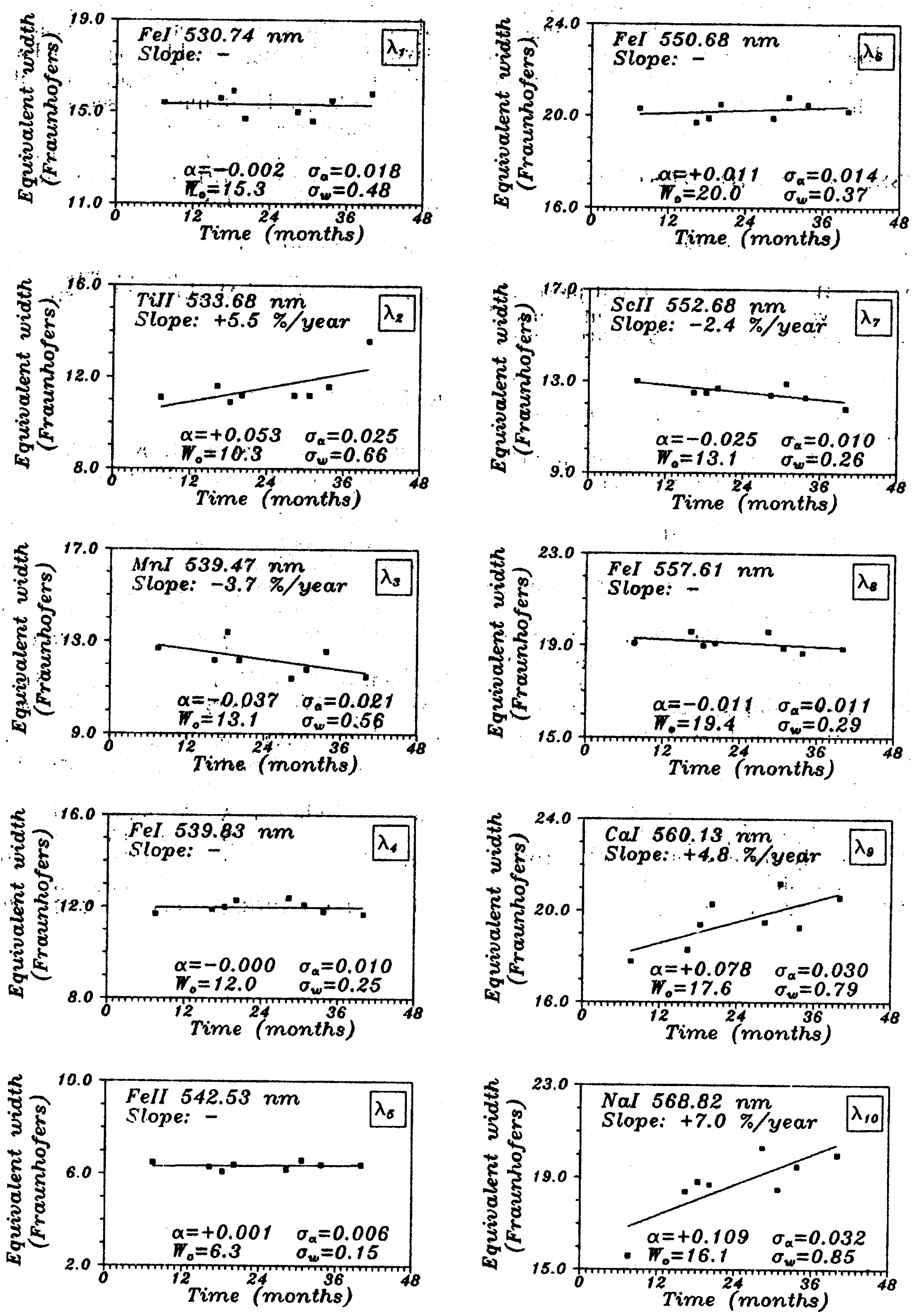

Fig. 4. Trend of changes of equivalent widths with the Solar activity.

After two iterations we selected five lines (λ_1, λ_4, λ_5, λ_6 and λ_8) with no significant change of equivalent widths. These lines are marked by full squares in Fig. 3 and are used for final determination of the coefficients $a^{(1,j)}$ and $b^{(1,j)}$.

3. DISCUSSION OF THE RESULTS

Using the inverse transformation procedure (3), reduced (free of systematic errors) values of equivalent width (W) were obtained and presented in Tab. 3. These values W are linear functions of time as shown in Fig. 4, and could be written in the form:

$$W = \alpha t + W_0, \tag{4}$$

where α has meaning of *monthly variation* of equivalent width in absolute scale.

Relative variation of W in percentage per year (*slope*) is calculated using the expression:

$$Slope = \frac{\alpha \times 12}{W_m} \times 100, \tag{5}$$

where $W_m = \alpha t_m + W_0$ is mean value of W for the time $t_m = (t_1 + t_8)/2 = 23.75$.

It is clear from Fig. 4 that five out of ten spectral lines do not show changes of W with activity within the $\pm\sigma$ error limit (the coefficient α should be compared to corresponding standard deviation σ_α). Three lines show steady and pronounced increase of W with activity:

λ_2=TiII 533.68nm (+5.5% per year),
λ_9=CaI 560.13nm (+4.8% per year) and
λ_{10}=NaI 568.82nm (+7.0% per year).

Two lines show steady decrease of W with activity:

λ_3=MnI 539.47nm (−3.7% per year) and
λ_7=ScII 552.68nm (−2.4% per year).

We would like to emphasize that all the spectral lines with positive trend of W with increase of activity (λ_2, λ_9, λ_{10}) could be considered as activity-sensitive lines because their slopes are well above 2σ level ($\alpha > 2\sigma_\alpha$). These lines are sensitive to changes in photospheric conditions (T, p, etc...).

Similar results were obtained by Stepanyan and Scherbakova (1979), Livingston and Holweger (1982) and Kokhan (1987).

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УТИЦАЈ СУНЧЕВЕ АКТИВНОСТИ НА ЕКВИВАЛЕНТНЕ ШИРИНЕ НЕКИХ ФОТОСФЕРСКИХ ЛИНИЈА

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Показане су промене еквивалентних ширина за десет изабраних спектралних линија (530.74 нм $\leq \lambda \leq$ 568.82 нм), према "Београдском програму за праћење активно-осетљивих спектралних линија Сунца као звезде", за период август 1987 – мај 1990.