SOME ASPECTS OF THE ANALYSIS OF VECTOR MAGNETOGRAMS AND APPLICATION TO COLLABORATED MEASUREMENTS

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ABSTRACT. In June 1983 simultaneous vector magnetograms were obtained with the magnetographs of the Potsdam Solar Observatory "Ensteinturm" and the Sayan Observatory (Irkutsk). For the study is selected the leading spot in the active region SD 164 (NOAA 4216) on June 24, 1983. Photographically measured field strengths (independent of stray light) were used as reference values for the stray light correction of the magnetographic data. A comparison of the magnetograms shows a good correspondence in the field strengths as well as in the field azimuths. The distributions of the verical field gradients dBz/dz and the vertical current densities were derived by approaching of the transverse field distributions by spline functions which are smoothed in relation to the measurement arrors. The mean vertical gradients in the umbra were found to be about 0.32 G km^{-1}. The distribution of the vertical gradients reflects a return flux topology of the magnetic field around the spot. The distributions of the vertical current densities show a good correspondence also. Up and downflowing currents correspond to clusters of field lines which nonradially run out the spot partly somewhat curled.

НЕКОТОРЫЕ ТОЧКИ ЗРЕНИЯ АНАЛИЗА ВЕКТОРНЫХ МАГНЕТОГРАММ И ИХ ПРИМЕНЕНИЕ К ИЗМЕРЕНИЯМ, КОТОРЫЕ БЫЛИ ПОЛУЧЕНЫ В РАМКАХ СОТРУДНИЧЕСТВА: Одновременные наблюдения полного бектора были получены магнитографами Потсдамской солнечной Обсерватории "Эйнштейнтурм" и Саянской Обсерватории (Иркутск) в июне 1983 г. Для исследований было выбрано ведущее пятно активной области СД 164 (НОАА 4216) 24 июня 1983 г.. Напраженности поля, которые были измерены фотографическим методам (они независят от рассеянного света), были использованы как стандард при исправлении магнитографических данных за рассеянный свет. Сравнения магнитограмм обоих обсерваторий показали довольно хорошое совпадение напряженностей и азимутов магнитного поля. Распределения градиентов продольного поля dBz/dz и плотности вертикальных токов были вычислены использованием приближенного распределения поперечного поля. Приближение проведено функциями "сплейн" сглаженными относительно погрешностей измерений. Среднее значение продольного градиента было 0.32 Г/км в тени пятен. Распределение градиентов отражает топологию магнитного поля вокруг пятна с обратно направленными магнитными трубками. Распределение плотности продольного тока обоих обсерваторий тоже показали хорошое совпадение. Вверх и вниз направленные токи относятся к совокупностям магнитных силових линий выходящие из пятна нерадиально.

URČITÉ HĽADISKÁ ANALÝZY MÁP VEKTORA MAGNETICKÉHO POĽA A ICH VYUŽITIE PRI MERANIACH ZÍSKANÝCH V RÁMCI SPOLUPRÁCE: **Na magnetografoch Slnečného observatória v Potsdame (Einsteinturm) a Sajanského observatória pri Irkutsku boli simultánne v júni 1983 získané mapy vektora magnetického poľa. Pri štúdiu bola vybraná vedúca škvrna aktívnej oblasti** SD 164 (NOAA 4216) z 24. júna 1983. **Fotograficky merané** magnetické intenzity (tieto nezávisia od rozptýleného svetla) boli použité ako referenčné hodnoty pre opravu magnetografických údajov o rozptýlené svetlo. Magnetogramy obidvoch observatórií sa dobre zhodujú tak v hodnotách indukcie ako aj v azimutoch magnetického poľa. Rozdelenie gradientov vertikálnej zložky indukcie dB_z/dz a vertikálnych hustôt toku boli vypočítané z rozdelenia transverzálneho (priečneho) poľa. Priblíženie k tomuto rozdeleniu bolo uskutočnené pomocou "spline" funkcií, ktoré sú vyhladené vzhľadom na chyby merania. Stredná hodnota vertikálneho gradientu v umbre je 0.32 G km^{-1}. Rozdelenie vertikálnych gradientov je zrkadlovým obrazom topológie magnetického poľa okolo umbry s opačne smerovanými magnetickými trubicami. Rozdelenie hustoty vertikálneho prúdu je pre obidve observatóriá v dobrej zhode. Prúdy smerujúce hore i dolu odpovedajú siločiaram, ktoré neradiálne vychádzajú zo škvrny a sú čiastočne zakrivené.

1. OBSERVATIONS

In June 1983 cooperative magnetografic observations were made within a KAPG-Theme 4.1. observational program. Target of the program was the group Solnechnye Dannye 164/83 (NOAA 4216, Mt. Wilson 23713), located at 17° N, 106° in Carrington longitude. An overviews magnetogram of the region on June 24, 1983 is given in Figure 1.

In this paper will be regarded the leader spot only and all shown Potsdam magnetograms are cut outs of magnetograms of the whole region. In Table 1 are given the magnetograms selected for this study.

Additionally is included a cut out of the Ondrejov Magnetogram on June 24 (7:10 - 8:00 UT) in the comparison of longitudinal field strengths.

Table 1
Data of the used vectormagnetograms

Disignation (Date)	Time (UT)	Line (Å)	Observatory
830624.01	6:07 - 6:24	FeI 5253	Potsdam
830624	6:58 - 7:12	FeI 5250	Sayan (Irkutsk
830624.03	9:29 - 9:49	FeI 5253	Potsdam

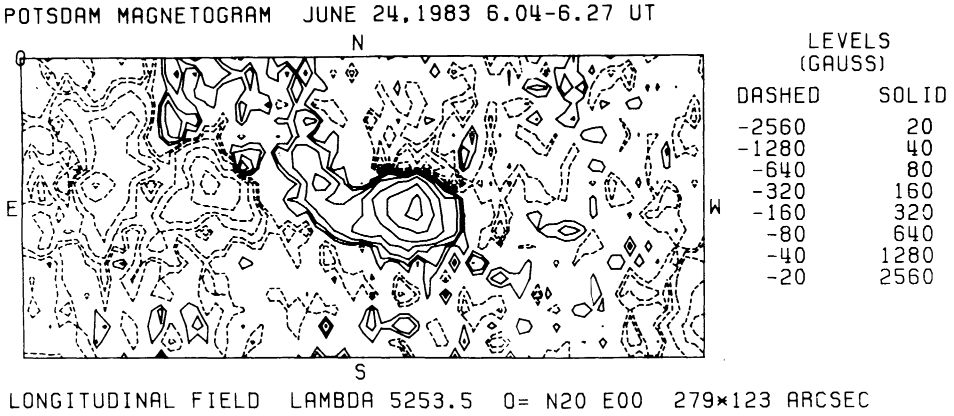

Fig. 1: (a) Map of longitudinal field in the active region SD 164/83

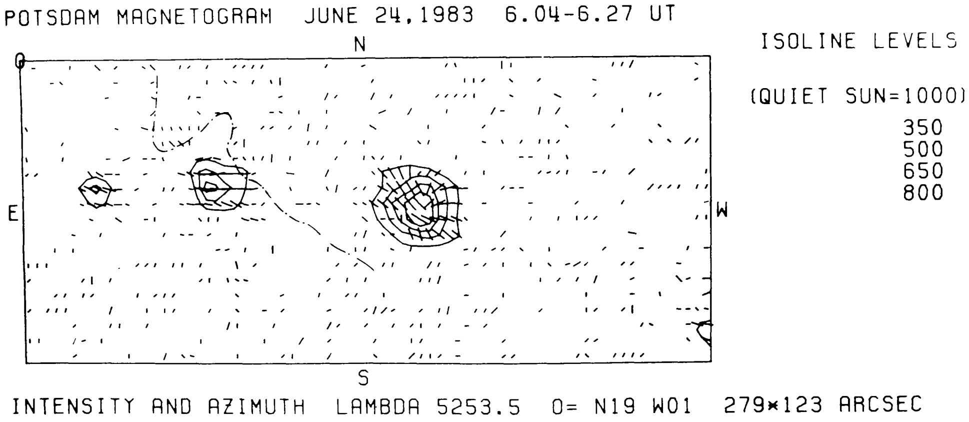

Fig. 1 (b) Map of the intensity (isolines) and direction of the transverse field. The length of the line segments corresponds with the transverse field strength in a logarithmic scale.

2. PREPARATIONS OF MAGNETOGRAPHIC DATA

One of the main external disturbances of magnetographic measurements is given by stray light. It is difficult to eliminate exactly these disturbances without direct measurements of the stray light parameters. For this study field strengths in the leader spot, measured by Künzel (1983) using the photographic method at one of the horizontal telescopes at Ondrejov, were used as reference values because this method is not influenced by stray light. Figure 2 shows the photographic measured maximum field strengths and the mean of five magnetographic measured maximum field strengths (full vector) in the leader spot before and after the correction. We can see that the values of the

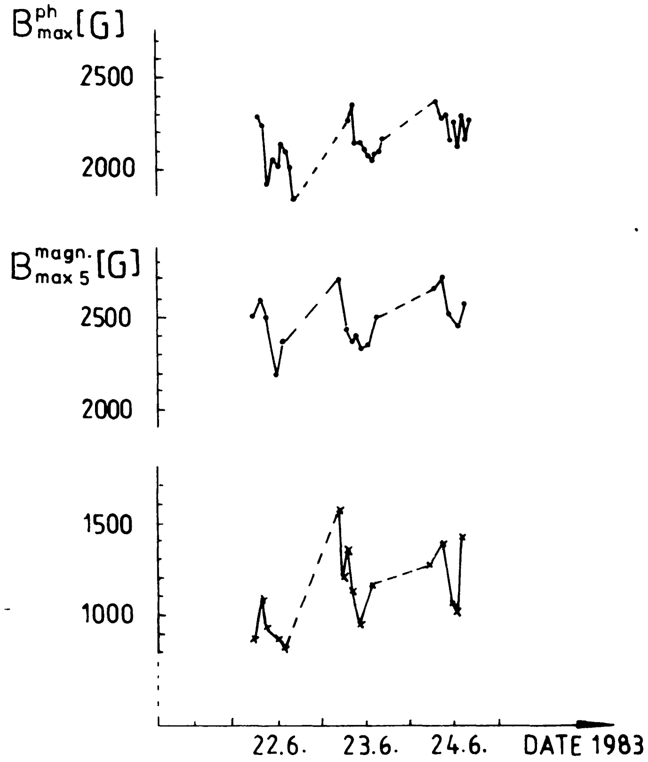

Fig. 2: Graphs of the photospheric measured maximum field strengths (upper) and the mean of five magnetograpfic measured maximum field strengths before and after (middle) the stray light correction.

magnetographic measured field strengths and their variations are more realistic after the correction. Also the mean umbra intensities (not shown here) have only insignicant fluctuations during one and the same day (but they can change from one day to the next), which was an additional criterion of the correction procedure. The instrumental polarization was eliminated as described by Bachmann et al. (1984).

3. COMPARISON OF THE MAGNETOGRAPHIC DATA

Comparison of simultaneous magnetograms obtained with different magnetographs are important to see the reliability of the observations and to give information about the accuracy of each magnetograph.

Using the integral method as described by Pflug and Hofmann (1977) Figure 3 shows the longitudinal field strengths measured in Irkutsk (Sayan), Ondrejov and Potsdam with respect to a mean field distribution of the three mag-

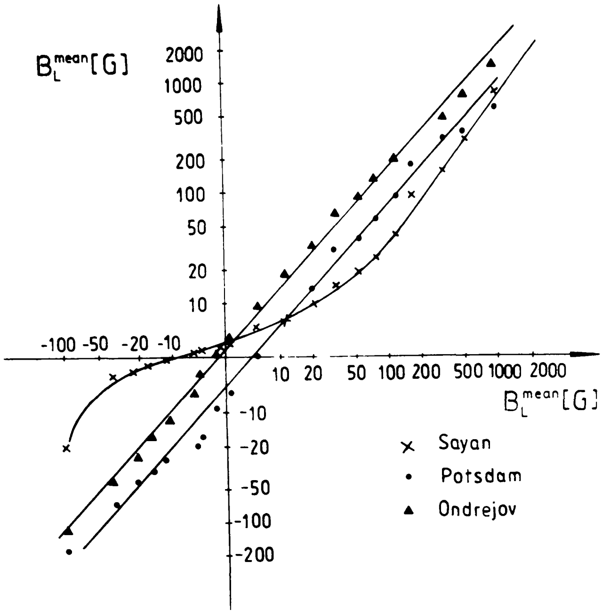

Fig. 3: **Relation of the longitudinal field strengths.**
Ordinates: magnetic field strength of the measured data,
Abscissa: mean magnetic field strength of all data.

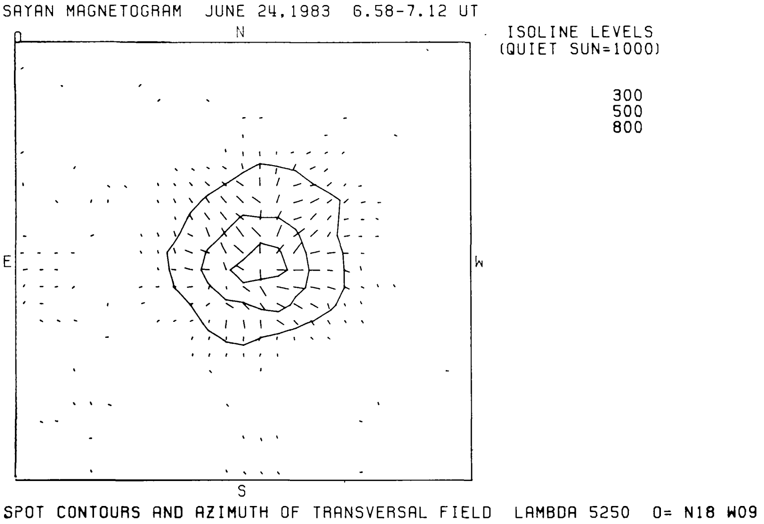

Fig. 4: **Azimuth of the transversal field**
(a) Sayan-observatory

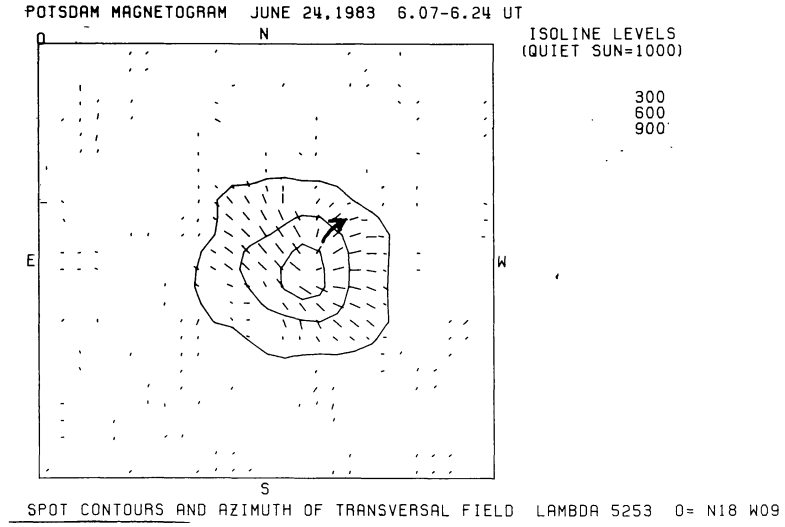

Fig. 4: Azimuth of the transversal field
(b) Potsdam

netógraphs. There are differences between the zero point levels up to 12 G and a factor up to 3 between the scales. These deviations are comparable with the

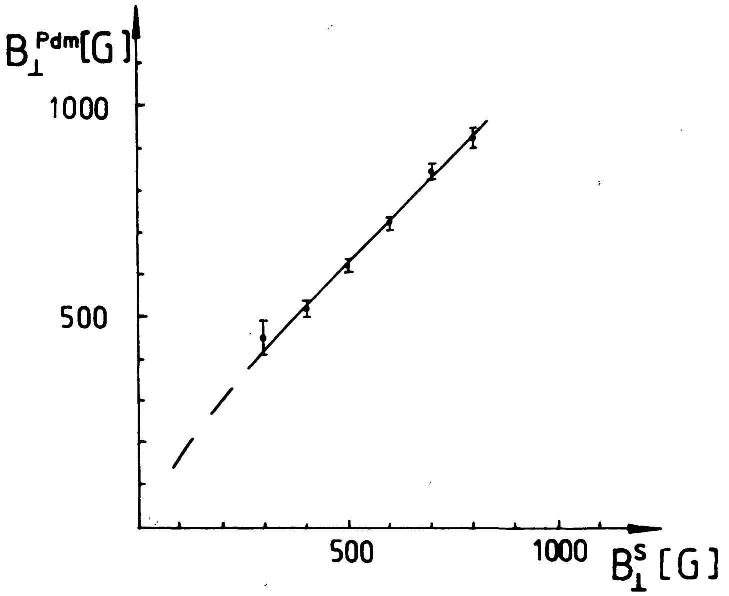

Fig. 5: Relation of the transverse field strengths
Ordinates: magnetic field strength of the Potsdam data.
Abscissa: magnetic field strength of the Sayan data.

netographs. There are differences between the zero point levels up to 12 G and a factor up to 3 between the scales. These deviations are comparable with the results of other authors (Beckers, 1973; Pflug and Hofmann, 1977). Restricting we must notice that the number of points (802) is not large enough for this statistic method, especially for the negative (south polarity) values. The azimuths of the magnetic field are shown in Figure 4. A quick look shows a good correspondance. Both magnetograms show the same tendency for the field lines to concentrate in clusters which probably are connected with different elements of the active region (Grigorjev et al., 1983). The relation of the transverse field strengths shown in Figure 5. The relation is also derived by the integral method and shows a good agreement if we take into consideration that both lines have a different sensitivity to temperature what will be of high importance in the penumbra, which occupies a considerable area in the magnetogram.

4. DERIVATION OF VERTICAL GRADIENT AND CURRENT DENSITY

With magnetographs the magnetic field distribution is measured in general in the photosphere. To understand many problems of solar activity and the connected processes it is important to know how the field continues into the upper atmosphere and how the current system is builded up in these layers. Using the Maxwellian equations

$$\mathrm{div}\,\vec{B} = 0$$

$$\mathrm{rot}\,\vec{B} = \vec{j}$$

the knowledge of the horizontal distribution of the transverse magnetic field's components allows calculations of the vertical gradient of B_z and the vertical current density:

$$Bz/\partial z = -(\partial Bx/\partial x + \partial By/\partial y)$$

$$jz = (\partial By/\partial x - \partial Bx/\partial y)/\mu_0$$

In many earlier studies difference approximations were used for the spatial derivatives of the transverse field. Then the accuracy of jz is significantly influenced by the large measurement errors of Bx and By. Therefore I approaches the field distribution by spline-functions which are smoothed in relation to the measurement errors. Using the spatial derivatives of these functions in each pixel the vertical gradient and the current density was then calculated over the magnetographs field of view. Based on this technique the noise level in $\partial Bz/\partial z$ and jz was determined to be less than 0.04 G/km^{-1} and $3\ 10^{-3}$ A/m^2, respectively.

5. VERTICAL GRADIENTS

The distribution of the vertical gradient in the spot in shown in Figure 6. There is an area of gradient with opposite sign to Bz in the umbra and in-

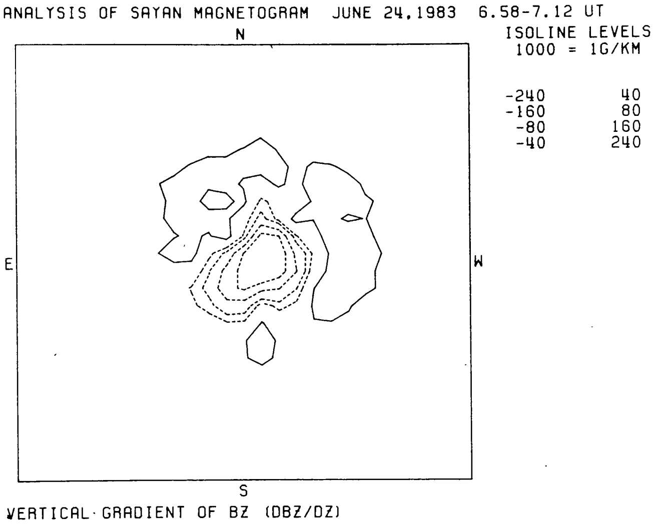

Fig. 6: Vertical gradients of Bz. (a) Sayan-observatory

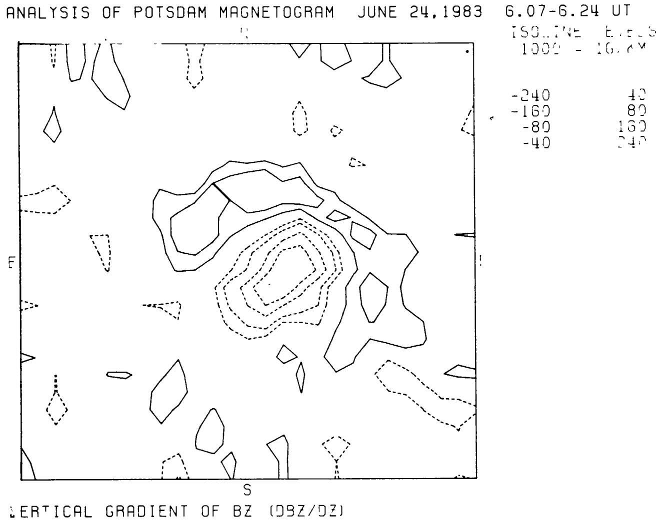

Fig. 6: Vertical gradients of Bz. (b) Potsdam

ner penumbra. The numerical values are given in Table 2 for the three used magnetograms.

Table 2

Observed vertical gradients of sunspot magnetic field obtained from div$\vec{B}$ = 0

observation	$\left\vert\frac{\partial Bz}{\partial z}\right\vert$, G km^{-1} (maximum value) -	$\left\vert\frac{\partial Bz}{\partial z}\right\vert$, G km^{-1} (average of the 5 maximum values around the spot axis)
830624.01	0.37	0.34
830624	0.42	0.33
830624.03	0.33	0.30

The gradients obtained with both magnetographs agree very good, in so referring to the good correspondence between the measured transverse fields. The values are in the range as found by other authors (0.1 - 0.7 G km^{-1}) from divB = 0 (cf. Obridko and Teplitskaya, 1978, and Hagyard et al., 1983). The gradient decreases with the radius of the spot, becomes zero near the penumbral edge, and from east via north and west to southwest a circle like area of opposite sign surrounds the penumbra.

This area reflects a phenomenon observable mainly by a class of old spots (Liggett and Zirin, 1983) which are surrounded by bright rings in Hα and K-line and a weak opposite field region. Osherovich (1982) has elaborated a magnetohydrostatic model (Return Flux Model) of sunspots which give a possible topology, interpreting this type of observations. The field lines starting in the penumbra re-entering the photosphere in the immediate surrounding of the sunspot. An upper limit for $\partial Bz/\partial z$ in the center of a sunspot can be derived for this model (Osherovich, 1984). In our example (radius of the outer boundary of the penumbra $r_p \approx 14700$ km, Bz$\approx$2200 km) the upper limit amounts 0.63 G/km.

6. CURRENTS

The return flux phenomenon supposed in section 5 can also be understood in terms of currents. Inside the spot azimuthal currents flow across the magnetic field in accordance with the right-hand rule, i.e. the azimuthal current has the same sign as the vertical field Bz. At low heights the azimuthal current becomes zero mear the outer penumbral edge and flows in the reverse direction outside the penumbra because the opposite directed field. Similar results are found through theoretical calculations by Ding et al. (1985) who investigated the currents in a unipolar sunspot with a model of a cylindrically symmetric magnetic field.

In the spot under study there are deviations from the radial in the observed transverse field, which are sources of additional vertical currents flowing through the photospheric surface of the spot. Figure 5 shows this currents derived from the transverse field (cf. Figure 4). There are areas of up

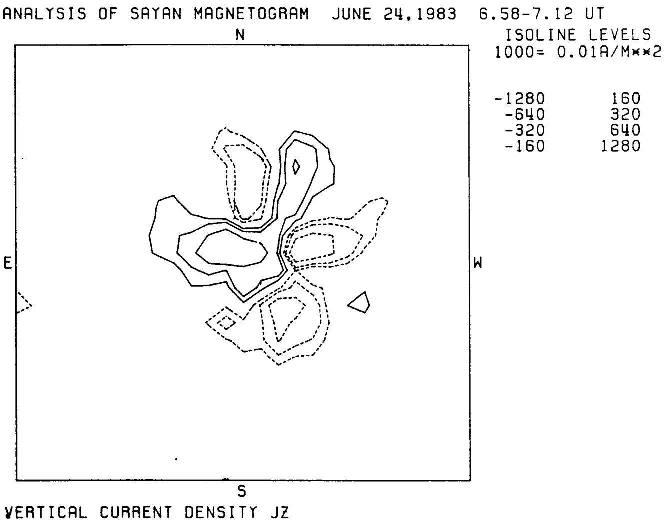

Fig. 7: Vertical current density. (a) Sayan-observatory

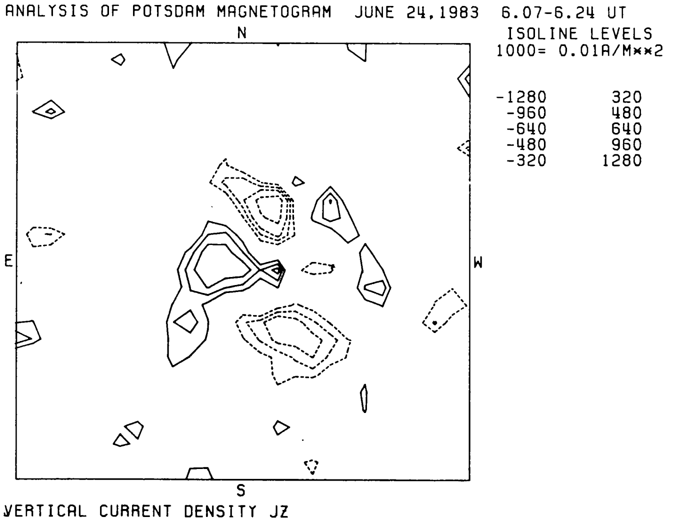

Fig. 7: Vertical current density. (b) Potsdam

and downflowing currents. These correspond to cluster of field lines which nonradially run out the spot partly somewhat curled (cf. arrows in Figure 4).

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I would like thank the colleagues who place at my disposal their observations, especially Dr. V.M. Grigoryev and V.L. Selivanov (both Irkutsk) and Dr. M. Klvaňa (Ondřejov); and to J. Rendtel for reading the manuscript.

CORRECTION

In Figure 2 the ordinate of the middle graphs is 500 G higher as correct. The correct scale are 2000 instead of 2500 and 1500 instead of 2000.

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