ABOUT THE RELATION BETWEEN THE LIMB EFFECT OF THE REDSHIFT ON THE SUN AND THE LARGE-SCALE DISTRIBUTION OF SOLAR ACTIVITY

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Abstract. The measurement of the magnitude of the limb effect was homogenized in time and a recurrent period of maxima of 27.8 days was found. A relation was found between the maximum values of the limb effect of the redshift, the boundaries of polarities of the interplanetary magnetic field, the characteristic large-scale distribution of the background magnetic fields and the complex of solar activity.

Systematic measurements of radial velocities on the Sun carried out at the Mt. Wilson Observatory in the years 1966–1968 and processed and published by Howard and Harvey (1970) indicate that the difference of the redshift between the limb and the centre of the solar disc usually changes day by day. The theoretical models as proposed by Schröter (1957) and Hart (1974) do not, however, give a satisfactory explanation of these fast changes. As follows from the study by Howard (1971) series of values indicating the magnitude of the limb effect show, during the autocorrelation analysis, long-term persistent regular recurrences with a period which is practically identical with the period of solar synodic rotation, i.e. about 27–28 days. We can, therefore, expect a characteristic relation between the typical changes of the limb-effect magnitude and the regularities in the large-scale distribution of solar activity, i.e. the photospheric background magnetic fields, the typical incidence of filaments, the structure of the boundary of interplanetary magnetic fields polarities etc. If such a relation could be found, it would be very interesting, especially since Howard interprets the changes of the limb-effect magnitude as a consequence of nearly horizontal large-scale velocity fields in the solar photosphere.

As the material of Howard and Harvey (1970) contains – for the chosen time interval – sequences of days when observations could not be realized, it is not homogeneous in time and thus not convenient for direct comparison.

The primary assumption for the elaboration of the method for processing the measured data is based on Howard's finding of persistent recurrences in the change of the limb-effect magnitude. The aim of processing was to homogenize in time the series of the measured limb-effect magnitudes.

The measured values were therefore ranged in the 'solar calendar' with a recurrence of 27 days. The material thus covers 31 Bartels rotations from rotation No. 1821 to rotation No. 1852. In that way we have obtained a table where the columns were denoted by the index $i \sim 0, 1, 2, \ldots, 26$. The line index j had values (number of rotations) $j \sim 1821, 1822, \ldots 1852$. Each measured value of the limb effect can, therefore, be denoted by two indexes e_{ji}. For the purpose of time homogenization we have used the following algorithm:

$$e_{kl} = \frac{1}{X} \sum_{i=l}^{l+2} \sum_{j=k}^{k+3} e_{ji} ,$$

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where k reaches the values 1821, 1822,... 1849 and l reaches the values 0, 3, 6, 9,... 24. The value e_{kl} indicates the group average value of the limb effect and X is the number of measurements in one group. At the same time the value X indicates the relative statistical weight of the value e_{kl} homogenized in time.

As a result of this arrangement we obtain a matrix with 9 columns and 29 lines containing homogeneous in time and equidistant average values of the limb effect, while not all the values have the same statistical weight. The result of this procedure is graphically represented in Figure 1, where two subsequent 27-day intervals are

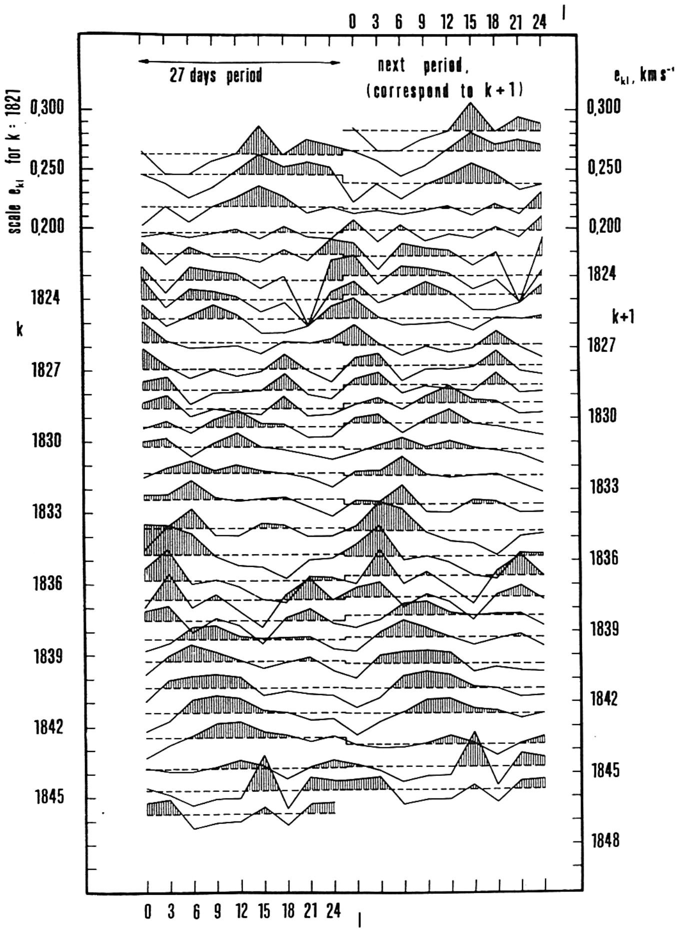

Fig. 1. Graphical representation of the shape of the e_{kl} value. Sections illustrating the 27-day interval are drawn side by side. Values above the average for 27 days are hatched.

always plotted side by side. The values larger than the average over 27-day intervals are hatched. We can see from the figure that the averaged value of the limb effect shows a marked variation and the above average values are ranged in a vertical stripe slightly inclined towards the vertical axis. The inclination corresponds to the

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recurrence of 27.8 days. Thus we might conclude that the changes of the parameter e_{kl} occur approximately in heliographic latitudes from 20° to 40°.

Figure 2 shows the distribution of polarities and of the boundaries of the interplanetary magnetic field sectors ranged, according to Bartels. Rotations as measured by satellites (Wilcox and Colburn, 1970) are hatched (positive polarity is vertically hatched, the negative polarity is horizontally hatched). The dark circles

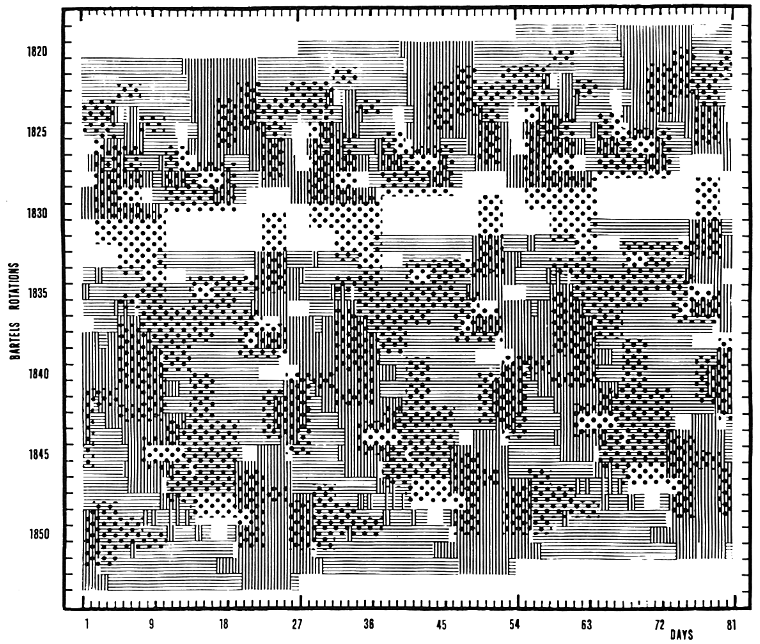

Fig. 2. Chart illustrating the relation between the above average values e_{kl} (the zones in Figure 1 are hatched, here they are represented by dark circles) and the distribution of polarities of the interplanetary magnetic field measured by satellites. The positive polarity is horizontally hatched, the negative one vertically.

indicate the distribution of the above average values of the averaged limb-effect magnitude. The plot of the limb-effect values is shifted by 4.5 days in the time direction to reduce the time difference of the solar wind flight from the Sun to the Earth. The two plots are mutually superposed and are drawn three times side by side so that three rotations in one line are in a chronological sequence. In the figure we can clearly see the systematic incidence of the above average limb-effect magnitude in the close vicinity of the polarities boundary during the transition from (+) polarity to (−) polarity. In the transition from (−) polarity to (+) polarity such a relation is far less marked.

In this connection we should quote the studies by Ambrož *et al.* (1971) and by Bumba (1972a, b) dealing with the super-giant regular structures of the magnetic field whose characteristic dimension is comparable with the diameter of the solar disc. These structures contain both magnetic polarities, one of which is always prevalent. Bumba pointed out the relation between the structures with a prevalent negative polarity and with an increased incidence of the solar activity including large flares. Regular structures with the prevalent positive polarity are well correlated with the increased geomagnetic activity.

Experience acquired by the processing of the limb-effect values shows that on the Sun another measurable large dimensional physical parameter exists which has the dimension of velocity and behaves differently in relation to the type of transition between average polarities all over the solar disc.

In the last part of this study the variation of group average limb-effect values e_{kl} was compared with the large dimensional structure distribution of sunspots, filaments, and photospheric magnetic fields. Synoptic charts drawn in the Carrington's coordinate system were used for this comparison.

In Figure 3 we have illustrated a typical and relatively simple and synoptic situation in the time interval including Carrington's rotations No. 1537–1540. In the upper part we have a synoptic map of the sunspots created by the superposition of four Zürich heliographic maps. In a similar way the map of filaments on the basis of Meudon material was designed. The map of magnetic fields was designed by Stenflo (1972) as a sum of magnetic fields intensities in relation to their polarity after four rotations. The resulting positive polarity is vertically hatched, the negative one is horizontally hatched. In the graph 3d the above average values of the homogenized limb-effect magnitude are illustrated by hatching; we can observe one marked maximum. In map 3b a large typical filament wake was created in the same region of heliographic longitudes. This area is characterized by an increased production of filaments and by their intense development from the equator up to the latitudes ±50°. The incidence of sunspots is illustrated in Figure 3a. The distribution and the structure of the sunspot groups in the given area of longitudes are not, however, marked. The situation describing the distribution of magnetic fields can be found in map 3c. In the longitudinal region with an above average limb-effect value we can observe a typical configuration of the magnetic field. We observe an exceptionally enlarged surface of the average magnetic fields with intensities higher than ±2 G. These background fields reach up to the polar areas and as a rule fill even the area around the equator.

We have designed altogether about 7 of such series for the period covered by the measurement of the limb-effect magnitude. The relation found between the different expressions of the solar activity is a typical one and in fact it can be found in a more or less marked way during all the studied period.

The results of this preliminary study are therefore the following ones:

(a) The recurrence determined by the autocorrelation method was found, also using the 'solar calendar' method; the recurrence period can be more precisely determined as being 27.8 days.

(b) The recurrent maxima in the course of the limb-effect magnitude are topologically linked to solar surface phenomena and the recurrence is given by the solar rotation in the latitudes from 20 to 40 heliographic degrees.

(c) The longitudinal areas of the maximum limb-effect values are linked to those areas on the Sun where there occurs the boundary of polarities of the total average value of the magnetic field strength on the disc and consequently of the interplanet-

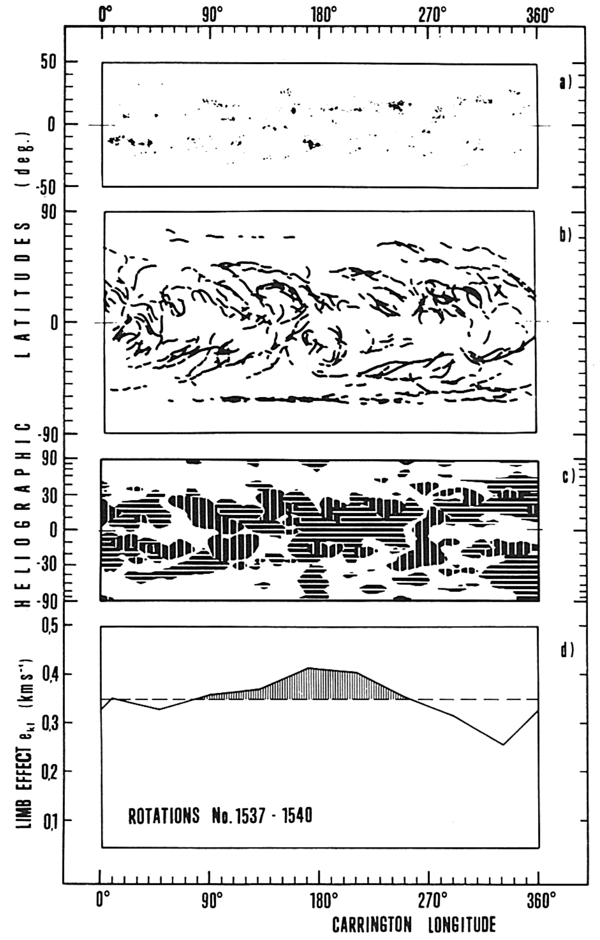

Fig. 3. Illustration of the relation between the sunspots distribution (map a), the filaments (map b) and the photospheric magnetic fields (map c). Values of the e_{kl} limb effect parameter above the average are hatched (plot d). In the figure the data from Carrington's rotations 1537 to 1540 are superposed.

ary magnetic field. The effect is much more marked at the boundary of the type (+ −) than at the boundary of the type (− +).

(d) On the solar surface such areas are characterized by an extensive complex of activity whose typical feature is especially a complex structure of the photospheric background magnetic fields reaching not only the active zone but also the polar and equatorial areas. As a rule one polarity then passes from one hemisphere to the other one. The complex magnetic structure is accompanied by the incidence of active regions and especially by the filament formation creating usually filamentary systems having a long life and development.

(e) The maximum average values of the limb effect have, therefore, a close relation to the large-scale distribution of the magnetic field and of the solar activity.

The chosen method is not, however, sufficient for the physical interpretation of this relation. A study oriented in this direction is under way and will be published in the *BAC.*

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DISCUSSION

Deubner: How can you distinguish changes of the limb effect from effects due to systematic vertical motions connected with active regions? Did you check whether an explanation of the observed changes in these terms would also be applicable?

Ambrož: The answer to the first part of your question is included in the paper by Howard and Harvey. It is very difficult to explain the physical origin of the limb effect. It seems very probable that the value of the limb effect is a super-position of the constant and variation term. But I cannot say more about the ratio of the horizontal and vertical component of the motion.

Karabin: How did you separate the limb effect from other velocities especially near the centre of the disc where the limb effect is small?

Ambrož: This separation was made by Howard and Harvey.