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ATOMIC ENERGY COMMISSION

RECURRENT FORBUSH DECREASES AND RELATIONSHIP BETWEEN ACTIVE REGIONS AND M-REGIONS

by

G. N. Shah, C. L. Kaul, H. Razdan and M. M. Bemalkhedkar
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ABSTRACT

Recurrent Forbush decreases and recurrent geomagnetic disturbances have been attributed to the solar M-regions, which are sources of high velocity solar plasma streams. A study of recurrent Forbush decreases for the period 1966-75 has been made to examine any possible relationship of M-regions with solar active regions. It is shown that at the onset of the recurrent Forbush decrease at earth, there is a high probability of encountering a class of active regions at central meridian of the sun which give rise to flares of importance $\geqslant$2B/3N. These active regions are found to be long-lasting and to have large areas as well as high H_α - intensities. Other active regions, producing flares of only lower importance, are distributed randomly on the sun with respect to the onset of a recurrent Forbush decrease. Using the quasi-radial hypervelocity approximation, the base of the leading edge of the high velocity stream, at the onset of a recurrent Forbush decrease at earth, is traced to the solar longitude about 40° west of the central meridian. From these results, it is deduced that M-regions are located preferentially to the west of long-lasting, magnatically complex active regions. Earlier studies of the identification of the M-regions on the sun have been re-examined and shown to conform to this positional relationship. A possible mechanism of the development of an M-region to the west of the long-lasting mangnetically complex active region is also discussed.

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1. INTRODUCTION

M-regions are the quasi-permanent regions on the sun, devoid of any visible features, to which the 27-day recurrent phenomenon in geomagnetic disturbances have been attributed (Bartels, 1932). The earlier study of a possible association between the recurrent disturbances and the various characteristic features of active regions in the photosphere, the chromosphere and the corona, led to the controversy as to whether M-regions are located in active regions (Mustel, 1964; Sarabhai, 1966; Couturier and Leblanc, 1970; Pathak, 1971), or tend to avoid them (Saemundson, 1962; Allen, 1964; Obayashi, 1964; Basler, 1966). From satellite observations, it is now becoming evident that M-regions indeed tend to avoid active regions. Snyder et al. (1963) have, in the first instance, shown from Mariner-2 observations the existence of corotating high-velocity solar wind streams and their association with the recurrent geomagnetic disturbances. From the measured solar wind velocity near the orbit of earth, they have further traced back the high-velocity streams and found that the stream location on the sun does not coincide with an active region (Snyder and Naugebauer, 1964). Roelof et al. (1975) support this view from Vela satellite observations. From the cross-correlation function between the coronal green-line intensity and the solar wind velocity, they have shown that the quasi-permanent green-line emission anticorrelates with solar wind velocity whereas transient, enhanced, green-line emission correlates with it. The regions of quasi-permanent low coronal green-line intensity are also shown to have an open magnetic field structure. From this, they conclude that M-regions and active regions indeed avoid each other. The earlier controversy has also been re-examined by Gulbrandsen (1974) in view of the recent satellite observations and shown that papers favouring a positive correlation between active regions and recurrent geomagnetic disturbances, can be more appropriately reinterpreted as indicating a negative correlation.

Recurrent geomagnetic disturbances are usually accompanied by recurrent Forbush decreases, as recorded by space-crafts (McCraken et al., 1966) and ground-based neutron monitors (Baliff and Jones, 1969; Kane, 1976); the decrease being attributed to the corotating high velocity solar wind stream associated with an M-region (Baliff et al., 1971; Bemalkhedkar et al., 1975). However, there is an indication that active regions may be associated in a complex manner with recurrent Forbush decreases (Antonucci et al., 1971; Bemalkhedkar et al., 1975). McDonald and Desai (1971) have also shown from Explorer XIV observations that the recurrent low-energy solar proton-events occur in association with recurrent Forbush decreases and recurrent geomagnetic disturbances and that the flux of such protons enhances when a flare takes place prior to the recurrent epoch.

The aim of the present work is to understand this possible association between active regions and M-regions from the correlated study of recurrent Forbush decreases and active regions. It is shown that the long-lasting huge complexes of activity that produce flares of importance $\geqslant$ 2B/3N, are preferentially near the central meridian of the sun when the recurrent event starts at earth. From the quasi-radial hypervelocity approximation (Nolte and Roelof, 1973a, 1973b), the leading edge of the associated corotating stream should, on an average, be located about 40^{o} west of the central meridian of the sun, from which it is concluded that M-regions lie to the west of huge complexes of activity. A number of earlier observations are shown to support such a conclusion.

2. RECURRENT FORBUSH DECREASES AND ACTIVE REGIONS

CRPL Reports reveal 112 recurrent Forbush decreases with decreases $\geqslant 2\%$ at Deep River and recurrence periods 27 ± 3 days, for the period 1966-75. These recurrent Forbush decreases have been considered for the study of their possible association with active regions on the sun. Active regions have been identified by flares whose heliographic coordinates and occurrence times within ± 100 hours of the onset of the recurrent Forbush decreases are recorded to study their distribution on the sun. From each McMath plage, only the highest importance flare has been considered and subsequent repetition of flaring neglected. The flare locations are next translated to the positions they would occupy at the onset of the recurrent event. In this manner, each McMath plage is located and counted just once, irrespective of the number of times it flares. Following this procedure and superimposing the distributions of active regions corresponding to the recurrent events, it is observed in Figure 1a that active regions which give flares of importance $<$ 2B/3N are distributed randomly in solar longitude at the onset of the recurrent event. On the other hand, the longitude-distribution of active regions which give flares of importance $\geqslant$ 2B/3N shows a prominent peak near the central meridian with half-width at half maximum equal to 42°(Figure 1b) and suggests that, statistically, these active regions may be related to the recurrent events.

There are, however, certain inherent limitations of this procedure. The translation of active regions to the positions they would occupy at the onset of the recurrent event may not always yield the actual distribution of active regions at the onset. For instance, those active regions are also included in the distribution which may have decayed away by the time recurrent event is observed at earth. Secondly, the restriction of observing the solar disc for a period of ± 100 hours of the onset implies that all solar longitudes are not observed for equal time intervals. The longitude range 35°E-35°W is observed for full 200 hours, whereas the ranges 36°E-90°E and 36°W-90°W are observed for progressively lesser time intervals; the observation period being only 100 hours at 90°E and 90°W. This is likely to introduce some bias in the distribution, in the sense that the active regions which flare only once during 200 hours are better identified in the longitude range 35°E-35°W. Our analysis shows that nearly 50 % of the active regions in Figure 1b give flares of importance $\geqslant$ 2B/3N just once during 200 hours of observations. Therefore, in order to ascertain that the peak in the distribution (Figure 1b) is not dominated by this time-bias, those active regions which give two or more than two flares of importance $\geqslant$ 2B/3N during 200 hours, have been separately plotted in Figure 1c. The peaking of this distribution also close to the central meridian, about 10°W, clearly shows that indeed a relationship between the active regions and the recurrent Forbush decreases does exist. In fact, the new distribution (Figure 1c) is more significant than the distribution of active regions in Figure 1b; the half-width at half maximum having reduced from 42° to 39°. Furthermore it has been observed that of the active regions which give only one flare of importance $\geqslant$ 2B/3N, a significant number of them were adjudged as giving the high importance flare by only one station and other stations recorded them as lower importance flares. In view of this, the large background in Figure 1b may be understood as due to the inclusion of a number of lower importance flares as well (compare with Figure 1a). In an attempt to understand further characteristics of the active regions that give flares of importance $\geqslant$ 2B/3N, the associated McMath plages have been investigated and reveals that these plages are mostly recurrent and possess high H_{α}- intensity and large areas as shown in Figures 2a, 2b. For comparison, the intensity and area distributions of a random sample of plages is also shown in the figures. Of the other known characteristics about such active regions are their long life-times, complex magnetic-field structures and an association with large sun-spot groups (Smith, 1963; Howard, 1963). Thus, the distribution in Figure 1c implies that only huge complexes of activity characterized by large areas, high intensities, long life-times and complex magnetic fields, are associated with recurrent Forbush decreases and tend to be preferentially near the central meridian at the onset of the recurrent event at earth.

3. RECURRENT FORBUSH DECREASES AND THE LOCATION OF M-REGIONS

A recurrent Forbush decrease is presumed to be the result of a depressed cosmic ray intensity in a high velocity solar wind stream corotating with the sun. The enhanced outward convection of cosmic rays in the high velocity stream, and the simultaneous inward diffusion, leads to a depressed intensity within the stream in a quasi-equilibrium state with a profile similar to a Forbush decrease (Axford, 1965; Matsuda and Sakurai, 1972). The decrease in earthbound monitors starts when the leading edge of the stream engulfs the earth. Here, it may be emphasized that the recurrent Forbush decrease takes place independent of a flare. A number of Forbush decreases can be cited in a recurrent series without a prior proper solar flare. A solar flare has otherwise been found to cause an enhancement of the depression of the recurrent Forbush decrease (Bemalkhedkar, et al., 1975). Therefore, starting with the premise that the corotating high velocity stream is the main source of a recurrent Forbush decrease series, the ensuing discussion attempts to locate the base of such a stream on the sun, from the knowledge of the onset of the decrease at earth.

Using the first interplanetary measurements of solar wind from Mariner-2, Snyder and Naugebauer (1964) traced back the corotating stream to its location on the sun, assuming the solar wind velocity to be constant and radial on its transit from the sun to earth. According to this assumption, the locus of the plasma emitted from the sun forms an ideal Archimedian spiral and, as such, for an average stream velocity of 600 Km/sec, the source location should be about 40° west of central meridian at the time the plasma element strikes the earth. Using this technique, they further show that such streams do not originate from the expected plage-regions and thereby conclude that either the approximation of assuming solar wind flow to be constant and radial is wrong or that the plage regions and solar wind streams are uncorrelated with each other.

The validity of the quasi-radial hypervelocity approximation (QRH), however, can be clarified by consideration of the results of the theoretical studies of Sakurai

(1971) and Matsuda and Sakurai (1972) in which it is shown that solar wind propogates radially at a constant speed beyond the magneto-hydrodynamic critical points. The QRH approximation consists of the assumption that beyond magneto-hydrodynamic critical points sonic and Alfven Mach numbers are large and that the effects of gravitational potential and azimuthal convection are negligible. Based on the estimates of Weber and Davis (1967) for the critical points and also on the extrapolation of observations near the orbit of the earth, Matsuda and Sakurai (1972) conclude that the QRH approximation assumptions are valid only for radial distances larger than 30 $R_\odot$ and that the solar wind streamlines within 30 $R_\odot$ are not defined by constant radial velocity approximation.

In a recent study, Nolte and Roelof (1973 a, 1973 b) have extended the results of QRH approximation within 30 $R_\odot$. Their study shows that the results of QRH approximation can be extended inside the release zone, where the competing effects of coronal corotation and inter-planetary acceleration tend to cancel each other, the former correcting the source location eastward and the latter westward. They further estimate that the error involved in locating the longitude of the position wherefrom the solar wind is released is only 10° and thereby suggest that the extrapolated QRH approximation can offer means to relate observed solar initial conditions in the release zone directly to the interplanetory measurements. Using this mapping technique, interplanetary observations have been successfully correlated with appropriate solar structures (Roelof et al., 1972 a; Krimigis et al., 1971; Roelof and Krimigis, 1972) and provide an experimental support to the validity of the technique.

Thus it follows from QRH approximation that the instantaneous ideal spiral field line connects earth to a location on the sun which is to the west of the central meridian. The exact location can be found accurately only if the measurements of plasma velocity and magnetic field in the streams are available. In absence of such measurements, however, a reasonable estimate can be made of the general location of M-regions from a knowledge of the average plasma velocity value in a corotating stream. For a plasma velocity of 600 Km/sec, the leading edge of the stream should be located about 40° west of central meridian. Furthermore, in absence of drastic variations in plasma velocity from its average value in a stream, it is evident that the leading edge of the corotating stream should always be to the west of central meridian at the time when its effect is seen at earth. It, therefore, follows that M-regions are preferentially located to the west of huge complexes of active regions.

The conclusion is valid, however, only statistically. Additional constraints on the selection criteria of active regions may be needed to arrive at a unique relationship of active regions with M-regions. But even without further constraints, the width of the distribution in Figure 1c can be explained by assuming that the separation between an active region and the leading edge of the M-region stream changes. The implication of the assumption that the stream width changes, has been recently shown to be true (Gosling et al., 1976).

4. DISCUSSION

Babcock and Babcock, as early as 1955, have observed that a large-scale photospheric region, having an overall single-polarity magnetic field, in or out, could be associated with a long-series of recurrent geomagnetic storms in the year 1952-53. Subsequent observations of the interplanetary magnetic field (Wilcox and Ness, 1965) showed that the high velocity recurrent stream, contained in one of the sectors of the interplanetary magnetic field, was indeed responsible for the recurrent geomagnetic storm of Dec. 2, 1963. The recently discovered coronal hole, characterized by low X-ray and green-line emission and divergent, single-polarity magnetic field (Munroe and Withbroe, 1972; Altschuler et al., 1972), has been found to be the source of high velocity recurrent stream

(Kreiger et al., 1973 ; Timothy et al., 1975). The observed features of the coronal hole are, in fact, expected from the studies of Billings and Roberts (1964), Davis (1965), Pneuman and Kopp (1971), Gosling et al. (1972), Pneuman (1973) and Noci (1973) for it to be the source of high velocity recurrent streams. An open, single-polarity field structure has now been established to be an essential feature of solar regions responsible for high velocity solar wind streams. When seen in this perspective, our results imply that open and single polarity magnetic field structures exist preferentially to the west of huge complexes of active regions. This result is supported by the Mariner-2 and Imp-1 observations that regions of low green-line intensity (L-zones) lie to the west of regions characterized by high green-line intensity (Gulbrandsen, 1975). The observations of Snyder and Naugebauer (1964) and Obayashi (1964) also conform to this view. Furthermore, the model proposed by McDonald and Desai (1971) of the confinement of solar flare protons in closed magnetic field configurations over an active regions, wherefrom they leak subsequently during next few solar rotations from the preceding portion, is in agreement with our results, because it is mostly in the preceding portion (west)of an active region that open field structure is present, which facilitates the escape of particles from active regions.

The interesting feature of our observations that only those sites that give flares of importance $\geqslant$2B/3N tend to be near the central meridian of the sun at the onset of the recurrent Forbush decreases, suggests some uniqueness about these active regions. Although, it has been earlier pointed out in this work that the higher importance flares mostly take place in huge complexes of activity, the exact manner in which these activity centres are responsible for the existence of M-regions to their west is unclear. The answer seems to lie partly in the finding that, over extended periods of time, solar activity clusters in two longitude zones 180°apart, the central meridian passages of the zones coinciding with M-type disturbances (Dodson and Hedeman, 1967; Shah et al.,1977). An example of this is depicted in Figure 3 for 20 solar rotations for the period; Jan. 6, 1969 to June 29, 1970. The horizontal axis represents solar longitudes, with zero longitude at the far right end, and vertical axis the edge of the M-region on the sun, their location being arrived at using QRH approximation for a stream velocity of 600 Km/sec. From the diagram it is obvious that, for a majority of events, the leading edge of the M-region crosses central meridian earlier than the associated active region in the two longitude belts. Furthermore, it is noticed that as the solar rotation number increases, the active regions shift eastward by an average value of 6°per rotation indicating that after the decay of old active regions, new active regions develop predominantly to the east of previous locations. It is, therefore, believed that an M-region or a region of open field structure develops at the location of previous active regions, and it becomes understandable as to why M-regions should be found predominantly to the west of long-lasting active regions. The time history of a coronal hole studied by Timothy et al. (1975) corroborates this view. It is shown that the coronal hole observed on June 1, 1973 at 1423 UT, aboard Skylab, could be formed from the decaying of a long-lasting active region and that the eastern boundary of the hole was dominated by active region formations. Thus it seems that the formation of an M-region is linked with the understanding of the decay phase of long-lasting, huge complexes of active centres, giving rise to open field structures where high velocity streams originate.

REFERENCES

Allen, C.W., M-Regions, Planet. Space Sci., 12, 487, 1964.

Altschuler, M.D., Torotter, D.E. and ORall, F.Q., Coronal Holes, Solar Phys. 26, 354, 1972.

Antonucci, E., Castagnoli, G.Cini and Dodero,M.A., Effects of Active Regions on the galactic cosmic ray intensity, Solar Phys. 20, 497, 1971.

Axford, W.I., The modulation of galactic cosmic rays in the interplanetary medium, Planet. Space Sci., 13, 115, 1965.

Babcock, W. and Babcock, H.D., The Sun's magnetic field, Astrophys. J., 121, 349, 1955.

Baliff, J.R. and Jones, D.E., Flares, Forbush decreases, and geomagnetic storms, J.Geophys. Res., 74, 3499, 1969.

Baliff, J.R., Jones, D.E., Skousen, E.N. and Smith, D.T., Cosmic-ray decreases and the occurrence of solar flares, 76, 8401, 1971.

Bartels, J., Terrestrial-magnetic activity and its relations to solar phenomena, Terr. Magn. Atmospheric Elect. 37, 1, 1932.

Basler, R.P., The nature of solar M-regions, Planet. Space Sci. 14, 1193, 1966.

Billings, D.E. and Roberts, W.O., The origin of M-region geomagnetic storms, Astrophys. Norveg, 9, 147, 1964.

Bemalkhedkar, M.M., Razdan, H. and Kaul, C.L., Cosmic ray modulation by corotating solar streams in presence of flare plasma clouds, Proc. of the 14th Int. Cosmic Ray Conf., paper MG 4-5, 1975.

Couturier, P. and Leblanc, Y., On the origin of the solar wind velocity variations, Astr. Astrophys., 7, 254, 1970.

Davis, L., in R. Lust (ed.), Stellar and solar magnetic fields, North Holland Publishing Company, 1965, Amesterdam, Page 204.

Dodson, H.W. and Hedeman, E.R., Some patterns in the development of centres of solar activity, 1962-66, I.A.U.Symp. No. 35, 1967, Page 56.

Gosling, J.T., Hundhausen, A.J., Pizzo.V., and Asbridge, J.R., Compressions and rarefactions in the solar wind, J.Geophys. Res. 77, 5442, 1972.

Gosling, J.T., Asbridge, J.R., Bame, S.J. and Feldman, W.C., Solar wind speed variations: 1962-1974., J.Geophys. Res., 81, 5061, 1976.

Gulbrandsen, A., Coronal λ5303 intensity, geomagnetic activity and solar sources of high speed plasma streams, Planet. Space Sci. 22, 841, 1974.

Gulbrandsen, A., The solar M-Region problem - An old problem now facing its solution ?, Planet. Space Sci.,23, 143, 1975.

Goldestein, B.E., 'Nonlinear Corotating Solar Wind Structures', MIT Preprint CSR-P-71-63.

Howard, R., Magnetic observations relating to solar flares, Physics of solar flares, NASA, 1963, SP-50.

Kane, R.P., A comparative study of geomagnetic, interplanetary and cosmic ray storms, Preprint, CR-76-01, 1976, Physical Research Lab., Ahemdabad, India.

Krimigis, S.M., Roelof, E.C., Armstrong, T.P., and Van Allen, J.A., Low-energy ($>$ 0.3 MeV) solar particle observations at widely separated points ($>$0.IAU) during 1967, J.Geophys. Res., 76, 5921, 1971.

Krieger, A.S., Timothy, A.F. and Roelof, E.C., A coronal hole and its identification as the source of a high velocity solar wind stream, Solar Physics, 29, 505, 1973.

Matsuda, T. and Sakurai, T., Dynamics of the azimuthally dependent solar wind, Cosmic Electrodynamics, 3, 97, 1972.

McCraken, K.G., Rao, U.R., Bukata, R.P., Recurrent Forbush decreases associated with M-region magnetic storms, Phys. Rev. Letters, 17, 928, 1966.

McDonald, F.B. and Desai, U.D., Recurrent solar cosmic ray events and solar M-regions, J.Geophys. Res., 76, 759; 1971.

Munroe, R.H. and Withbroe, G.L., Properties of a coronal "hole" derived from extreme-ultraviolet observations", Astrophys. J., 176, 511, 1972.

Mustel, E., Quasi-stationery emission of gases from the sun, Space Sci. Reviews, 3, 139, 1964.

Noci, G., Energy budget in coronal holes, Solar physics, 28, 403, 1973.

Nolte, J.T. and Roelof, E.C., Large-scale structure of the interplanetary medium I: High coronal source longitude of the quite-time solar wind, Solar Phys., 33, 241, 1973.

Nolte, J.T., and Roelof, E.C., Large-scale structure of the interplanetary medium II: Evolving magnetic configurations deduced from multi-spacecraft observations, Solar Phys., 33, 483, 1973.

Obayashi, T., Corpuscular streams related to solar M-regions, Interunion Commission on Solar-terrestrial relations, Germany; 1964.

Pathak, P.N., Correlation of solar wind velocity with λ 5303 coronal intensity, Solar Phys., 20, 462, 1971.

Pneuman, G.W. and Kopp, R.A., Gas-magnetic field interactions in the solar corona, Solar Phys., 18, 258, 1971.

Pneuman, G.W., The solar wind and the temperature-density structure of the solar corona, Solar Phys., 28, 247, 1973.

Roelof, E.C., 1972 a, in C.Sonnet, P.Coleman, and J.Wilcox (eds.), Analysis and synthesis of solar and interplanetary energetic particles, plasma and magnetic field observations over three solar rotations, Solar Wind, NASA SP-308, Washington D.C., 140.

Roelof, E.C. and Krimgis, S.M., 1972, preprint, Applied physics Laboratory, the John Hopkins University, U.S.A.

Roelof, E.C., Cuperman, S. and Sternlieb, A., On the correlation of coronal green-line intensity and solar wind velocity, Solar Phys., 41, 349, 1975.

Saemundsson, T., Statistics of geomagnetic storms and solar activity, Mon. Roy. Astr. Soc., 123, 299, 1962.

Sakurai, T.K., Quasi-radial hypervelocity approximation of the azimuthally dependent solar wind, Cosmic Electrodynamics, 1, 460, 1971.

Sarabhai, V., Pai, G.L., Patel, D. and Pathak, P.N., Geomagnetic disturbance, plasma wind and solar activity, J.Geomagn. Geoelcct. 18, 157, 1966.

Shah, G.N., Razdan, H., Kaul, C.L., Distribution of solar active regions on the sun, Space Sci. Symp., VSSC, India, 1977.

Smith, H.J., Solar flares: Their structure, development, and motion, Physics of Solar flares, NASA, 1963, SP-50.

Snyder, C.W., Neugebauer, M. and Rao, U.R., The solar wind velocity and its correlation with cosmic-ray variations and with solar and geomagnetic activity, J.Geophys. Res., 68, 6361, 1963.

Snyder, C.W. and Neugebauer, M., The relation of Mariner-2 plasma data to solar phenomena, The proceedings of solar wind Conf., Caltech. U.S.A; 1964.

Timothy, A.F., Kreiger, A.S. and Vaina, G.S., The structure and evolution of coronal holes, American Science and Engineering Inc. ASE-3626; 1975.

Weber, E.J. and Davis, L., The angular momentum of the solar wind, Astrophys. J., 148, 217, 1967.

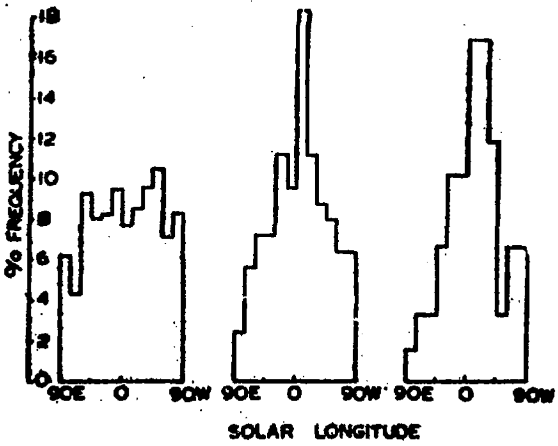
Wilcox, J.M. and Ness. N.F., Quasi-stationary corotating structure in the interplanetary medium, J.Geophys. Res., 70, 5793, 1965.

FIGURE CAPTIONS

Fig. 1: Frequency distribution of active regions on sun at the onset times of recurrent Forbush decreases. Fig. 1a corresponds to active regions producing only flares of importance $\leqslant$ 1B/2N, whereas Fig. 1b involves active regions producing flares of importance $\geqslant$ 2B/3N. In Fig. 1c only those active regions are included which give two or more flares of importance $\geqslant$ 2B/3N during ± 100 hours of the onset. The distribution in Fig. 1b and 1c have a prominent peak near the central meridian.

Fig. 2: Histograms of intensities (Fig. 2a) and areas (Fig. 2b) of Ca-plages of the active regions. The solid line distribution corresponds to active regions producing two or more flares during ± 100 hours of the Forbush decrease onset and the dashed distribution corresponds to a random sample of Ca-plages. The average intensity and area of plages associated with recurrent Forbush decreases is higher than that of the random sample.

Fig. 3: Longitude distribution of solar active regions for 20 solar rotations, for the period Jan. 6, 1969 to June 29, 1970. Existence of two belts of active regions, about 180° apart is obvious from the figure and have been marked by open and the dashed rectangles. An average eastward shift of 6°/solar rotation of the active regions, is also observed. The arrows represent locations of the leading edge of M-region streams, using QRH approximation for solar wind velocity of 600 Km/sec. The M-regions in most cases are to the west of active regions.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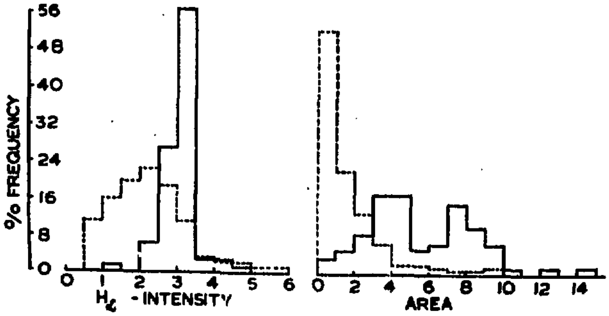
SOLAR LONGITUDE

a b c

Figure 1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AREA

a

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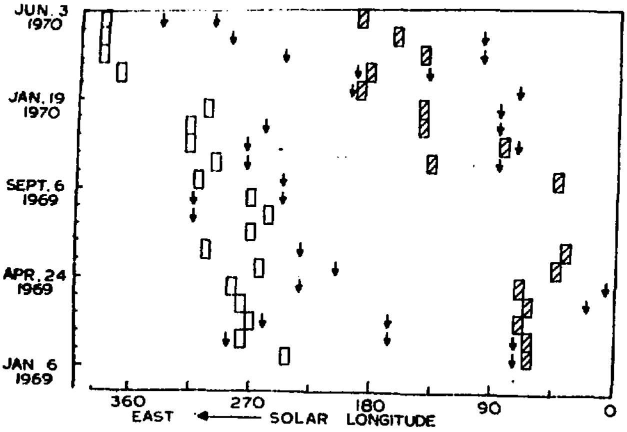
Figure 2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1969
360
270
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90
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EAST
SOLAR LONGITUDE

Figure 3