The Daily Variation of the Cosmic Ray Nucleonic Component at Murchison Bay and Uppsala

By ARNE ELD SANDSTRÖM, ERIC DYRING and STIG LINDGREN
Institute of Physics, University of Uppsala, Sweden

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Abstract

In both places the monitors were of the standard pattern with 12 proportional counters filled with 97 per cent enriched $B^{10}F_3$. The first and second harmonics of the mean daily variation have been determined both for yearly periods and for each sun rotation period. Vector sum diagrams for the first harmonics in the latter case are given covering the intervals 31 Aug. 1956 to 15 Aug. 1959 for Uppsala and 13 Sept. 1957 to 29 April 1959 for Murchison Bay. In some instances a considerable phase shift has taken place from one sequence of sun rotation periods to another. These phase shifts were not contemporary at the two stations. The first harmonic of the 12-month means displays a high degree of constancy with only a small secular phase shift. The amplitudes of the second harmonics are very small. Conditions are especially favourable concerning the deviation in the earth's magnetic field of the particles registered by the Murchison Bay monitor. Accordingly it has been possible to determine the direction of the anisotropy with a fairly good accuracy. The Murchison Bay records do not show any prominent phase shift with the K_p index. Concerning Uppsala, days with $[K_p]_{max} \leq 1^+$ have a later time of maximum than other days. The influence of single days with an abnormal daily variation is discussed.

Introduction

When plans were made for a Swedish arctic station during the IGY it was deemed essential to include a neutron pile monitor among the equipment for cosmic ray studies. The plans were realized through the Swedish-Finnish-Swiss IGY-expedition 1957—58 to Murchison Bay (Liljequist 1959). The site of the arctic station is on the island Nordaustlandet of the Svalbard (Spitzbergen) archipelago. Its geographic coordinates are 80° 03′ N and 18° 18′ E. It is nearly on the same meridian as the cosmic ray station at Uppsala (59° 55′ N and 17° 55′ E).

The continuous records from the Murchison Bay monitor start with Aug. 27, 1957. After the end of the Swedish-Finnish-Swiss IGY expedition the base was maintained for another year. However, owing to very adverse ice-conditions at the end of the 1958 summer it became impossible to refurnish the base with an adequate supply of diesel oil for the generators. As a consequence the continuous running of the latter had to end with April 1959. The first year's results from the Uppsala monitor have already been published (Sandström and Lindgren 1959).

Experimental details

Both monitors are of the type (Simpson, Fonger and Treiman 1953) recommended as the international standard instrument for the geophysical year. The few details in which the monitors differ from those of Simpson et al. were described in a previous paper (Sandström and Lindgren 1959). The monitor for the arctic station was designed in such a way as to make it possible to assemble the monitor for tests in the laboratory at Uppsala and then remove it in pieces to be reerected at Murchison Bay with the least possible trouble.

Although the site of the arctic station was in a region believed to be comparatively free from heavy snow falls, an iron scaffold was constructed to carry the monitor at a level well above the height of any snow drifts which might possibly collect along the walls of the C.R. building. The top of the scaffold consisted of a frame of beams supporting a thick wooden floor. The monitor itself stood on this floor. The roof of the building was given a shape expected to favour the snow being blown away by the prevailing winds. The scheme turned out very well. During the first year of recording the amount of snow staying on the roof never exceeded some few grams per cm^2. The mass of the heat insulated roof itself is less than 10 g/cm^2. Twice during the second year snow had to be removed from the roof.

The electronics of the Murchison Bay monitor is a true replica of that at Uppsala (Sandström and Lindgren 1959). The power was supplied by two diesel-engined generators, one of them always being kept ready to take over the load in an emergency.

As the research station at Murchison Bay included a very complete meteorological service and the pressure was registered in an adjacent building it was deemed quite unnecessary to equip the monitor with an instrument for independent barometric measurements. The general cosmic ray equipment includes an auxiliary recording instrument (Sandström and Lindgren 1959). From these auxiliary records the counting rates can be derived for periods of any length from half a minute to one hour.

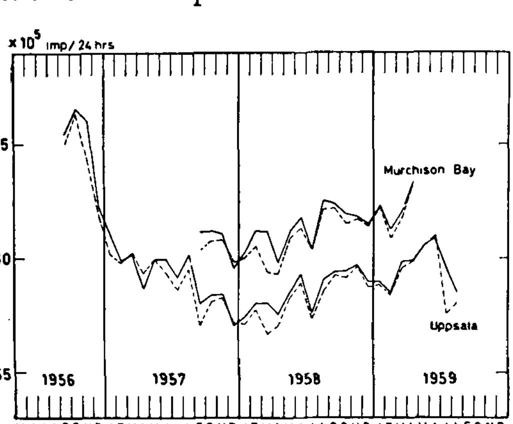

Fig. 1. Monthly means of the 24-hr values of the nucleon component in Uppsala and Murchison Bay. Full lines: days with $[K_p]_{max} \leq 3^+$. Dotted lines: all available days.

The monitors were calibrated by means of RaBe neutron sources of 1 mc. Calibrations were made whenever a readjustment of amplifiers or discriminators took place as well as after repairs or at any suspicion of a change of counting rate. No regular time schedule was followed as it was our aim to disturb the continuous performance of the monitors as little as possible. The two monitor sections were always calibrated separately. By limiting each calibration run to 25 minutes the whole calibration could be completed within one hour. This was necessary with regard for the continuity of the records as one section could not be calibrated without affecting the counting rate of the other. Likewise the neutron source affected the counting rate of the counter telescopes in the vicinity of the monitors.

With cadmium covers on the proportional counters the counting rate of the Uppsala monitor was 4 per cent of the normal counting rate with the cadmium tubes removed, while that of the Murchison Bay monitor was only 2.5 per cent. In both cases it was constant all along the plateau of the counters.

During Sept. 1957 the average counting rate of the Murchison Bay monitor was 420 c/min., while that of the Uppsala monitor was as low as 400 c/min. The Murchison Bay records cover the period of minimum intensity of the nucleonic component (Fig. 1) as well as what appears to be the start of a slow increase. The monthly averages appear to follow one another comparatively closely regardless of whether all days are included or only those with K_p indices less than 3^+.

In the records from Murchison Bay 17 days are affected by breaks of such an extent as tc make them unsuitable for harmonic analysis. For the same reasons 29 days have to be excluded from the Uppsala records between 1 Sept. 1957 and 31 Aug. 1959. For both monitors there are instances in which days could be saved for the harmonic analysis by interpolating values for single hours or, in a few cases, two consecutive hours. In no case single events or abrupt intensity changes are known to have taken place during the interval for which such an interpolation was performed.

All data have been referred to intervals of 2 hours. They have been reduced to an atmospheric pressure of 1,010 mb (the yearly average for Uppsala is 1,008 mb and that for Murchison Bay 1,012 mb). The pressure coefficient = 0.737 per cent/mb has been adopted for both the monitors (SANDSTRÖM 1958, SANDSTRÖM and LINDGREN 1959).

The daily variation

The yearly mean daily variations of the nucleonic component as recorded in Murchison Bay and Uppsala during the period 1 Sept. 1957 to 31 Aug. 1958 are shown in Fig. 2. The statistical variations are also plotted for each 2-hour interval. The figure displays how the points of measurement are distributed relative to the first and second harmonics. A corresponding diagram for the records from the Uppsala monitor from 1 Sept. 1956 to 31 Aug. 1957 has been published in a previous paper. A comparison does not display any differences in either phase or amplitude between the two yearly means as recorded by the Uppsala monitor. The points of measurement constitute a time series. Therefore, it is difficult to calculate the standard error for the amplitude as well as for the phase. In previous papers (SANDSTRÖM 1955, SANDSTRÖM and LINDGREN 1959), this difficulty was surmounted by exchanging the standard error for another limit of error. The latter was based on the assumption that the error in the differences between the daily mean and the number of pulses during each 2-hr period was twice the standard deviation of each point of measurement (SANDSTRÖM 1955). The error determined in this way will give a confidence of 90—99 per cent. It meets the purpose well when high confidence is desirable. However, comparisons become difficult with other papers, where, usually, limits of error are based only on the Poisson distribution of pulses. In the present paper we have therefore returned to this method of defining the accuracy.

At the same time it appears to us essential to determine the limits of error so as to correspond to real facts. This can be done by calculating the standard error from the residuals of the points of measurement after fitting the first harmonic, resp. the sum of the first and second harmonics. The deduction of the formulas for this error will be given elsewhere (DYRING and ROSÉN 1960). In some of the clock diagrams we have indicated this limit of error by dotted circles. It is our opinion that this kind of error should be employed for the calculation of significances rather than that deduced solely from an assumed Poisson distribution of pulses. The standard deviation of the points of measurement from the resulting curve will evidently include all statistical fluctuations. There is no constant relation between the two kinds of errors. That including all statistical fluctuations is usually bigger than that covering only the Poisson

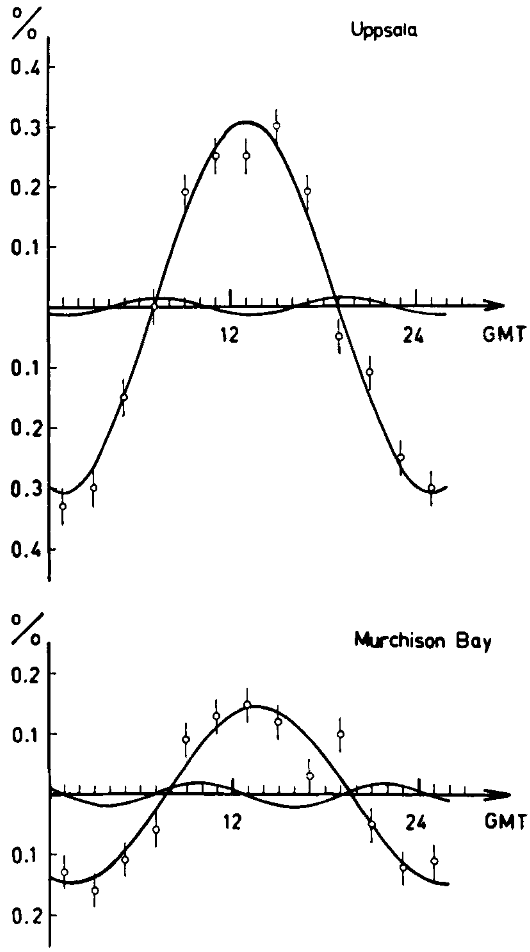

Fig. 2. First and second harmonics of the mean daily variation for 1 Sep. 1957 to 31 Aug. 1958 at Murchison Bay and Uppsala. The statistical fluctuations are indicated.

distribution. Concerning the additional variations we wish to remark that one of us (DYRING 1960) has found that the statistical fluctuations calculated according to Poisson's law have to be multiplied by a factor of 1.2 to cover the actual hour by hour fluctuations.

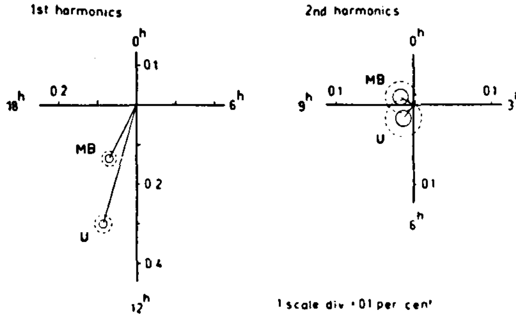

Fig. 3. First and second harmonics of the nucleon component 1 Sep. 1957 to 31 Aug. 1958. MB: Murchison Bay, U: Uppsala. Full circles: standard error from Poisson distribution. Dotted circles: standard error calculated from residuals after fitting first and second harmonics.

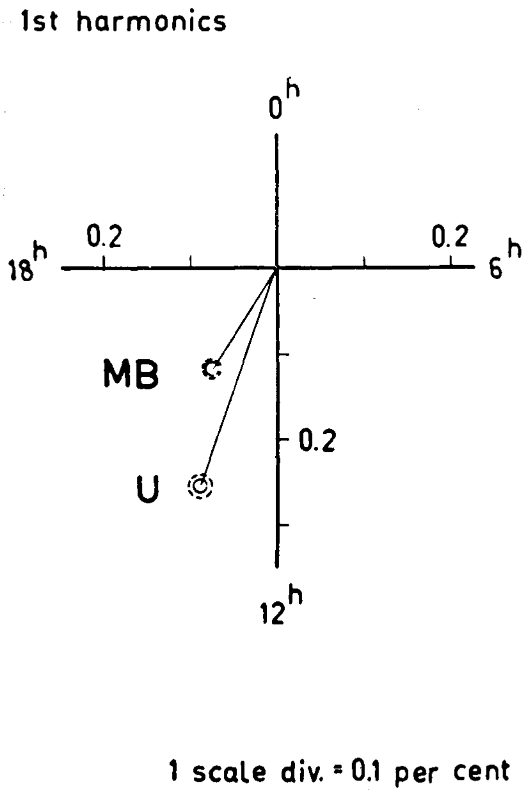

Fig. 4. First harmonics for the mean daily variation of the nucleonic component 26 Aug. 1957 to 30 Apr. 1959, MB: Murchison Bay, U: Uppsala. Full circles: standard error from Poisson distribution. Dotted circles: standard error calculated from residuals after fitting first and second harmonics.

The amplitude of the first harmonic is evidently smaller at the latitude of Murchison Bay than at the latitude of Uppsala. This is displayed also by the clock diagrams in Figs. 3 and 4. The phase difference is 45 minutes in both cases. A small phase shift is indicated by the records from the Uppsala monitor during three consecutive years (Fig. 5). The small amplitude at Murchison Bay causes an error in the time of maximum approximately twice as big as that affecting the time of maximum at

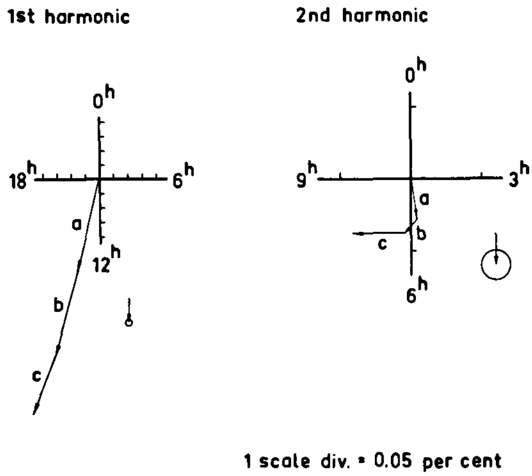

Fig. 5. Vector sum diagrams for the first and second harmonics of the nucleon component at Uppsala.
a: 1 Sep. 1956—31 Aug. 1957; b: 1 Sep. 1957—31 Aug. 1958; c: 1 Sep. 1958—31 Aug. 1959.

Uppsala. Concerning the phase difference between Uppsala and Murchison Bay it undoubtedly exists even with due regard for the wider limits of error deduced from the standard deviations of the points of measurement from the first harmonic (Fig. 3 and 4).

Turning to the vector sum diagram of the yearly means from Uppsala (Fig. 5) we note that a small but persistent phase shift is indicated during three consecutive 12-monthly periods. It ought to be remarked, however, that there appears to be a phase difference of 45 minutes between the two calendar years 1957 and 1958 (Table 1). This difference is far outside any limits of error. The reason for such a shift depending on the starting point for the twelve-monthly periods is more easily

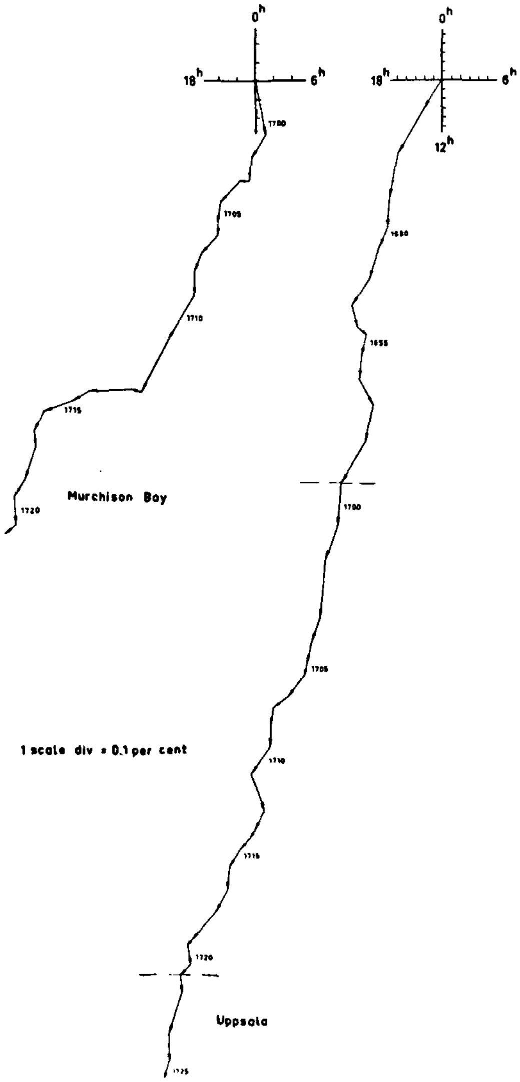

Fig. 6. Vector sum diagrams for the 27-day periods. The Murchison Bay vectors are twice the scale of those for Uppsala. The numbers denote sun rotation periods covering the following dates: 1690: 17 Dec. 1956—12 Jan. 1957; 1695: 1 May 1957—27 May 1957; 1700: 13 Sep. 1957—9 Oct. 1957; 1705: 26 Jan. 1958—21 Feb. 1958; 1710: 10 Jun. 1958—6 Jul. 1958; 1715: 23 Oct. 1958—18 Nov. 1958; 1720: 7 March 1959—2 Apr. 1959; 1725: 20 Jul. 1959—15 Aug. 1959.

understood after studying the vector sum diagrams in Fig. 6. These diagrams represent the phase and amplitude of the first harmonic of the mean daily variation for separate sun rotation periods. Naturally, the influence from the statistical fluctuations will be considerable although very few days had to be excluded. Although such an exclusion of a couple of days from a 27-day period usually does not affect the mean values of either the phase or the amplitude there are instances, especially during periods with a small amplitude, when a considerable change is caused by excluding only one single day (SANDSTRÖM and LINDGREN 1959). Therefore, the means for the sun rotation periods have been calculated using exactly the same days for both stations. In general the Murchison Bay records display a small amplitude. Consequently the random fluctuations will tend to mask most of the phase variations. For both stations it can be said that in most instances where there is a considerable variation in phase the amplitude is small and consequently the whole phase change can be regarded as due to a random distribution around a mean. In other instances the more or less persistent trend of the phase indicates variations which apparently are real.

The vector sum diagram for Murchison Bay displays a couple of very marked phase shifts. Starting with August and through October 1958 the phase differed definitely from that before as well as after this period. It appears

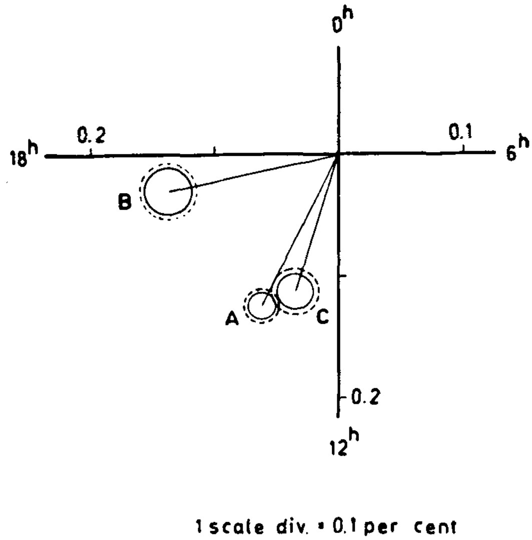

Fig. 7. Phase shifts of the first harmonic of the nucleon component registered at Murchison Bay. Full circles: standard error from Poisson distribution. Dotted circles: standard error calculated from residuals after fitting first and second harmonics.

A: 10 Oct. 1957—2 Aug. 1958; B: 3 Aug. 1958—18 Nov. 1958; C: 19 Nov. 1958—29 Apr. 1959.

Table 1. First and second harmonics of the mean daily variation.
The standard error of the amplitude calculated from the Poisson distribution of primary values ranges from 0.006 to 0.010. Calculated from residuals after fitting first harmonic it ranges from 0.008 to 0.020. Calculated from residuals after fitting first + second harmonics it ranges from 0.006 to 0.017 (Detailed tables complete with limits of error are distributed on application).

Station Int.number	Period	First harmonic		Second harmonic	
		Amplitude Per cent of daily mean	Phase GMT	Amplitude Per cent of daily mean	Phase GMT
Uppsala B 003	1 Sept. 1956—31 Aug. 1957	0.322	12 55	0 028	05 43
	Calendar year 1957	0.333	12 44	0.040	05 53
	1 Sept. 1957—31 Aug. 1958	0.306	12 57	0.014	07 24
	Calendar year 1958	0.219	13 29	0.009	09 54
	1 May 1958—30 Apr. 1959	0.217	13 29	0.030	08 42
	1 Sept. 1958—31 Aug. 1959	0.222	13 24	0.036	09 02
	26 Aug. 1957—30 Apr. 1959	0.263	13 15	0.020	07 34
	1 Sept. 1956—31 Aug. 1959	0.283	13 03	0.018	07 33
Murchison Bay A 010	1 Sept. 1957—31 Aug. 1958	0.147	13 40	0.020	09 56
	Calendar year 1958	0.131	14 31	0.019	01 25
	1 May 1958—30 Apr. 1959	0.131	14 14	0.027	03 46
	26 Aug. 1959—20 Apr. 1959	0.139	14 06	0.008	04 22

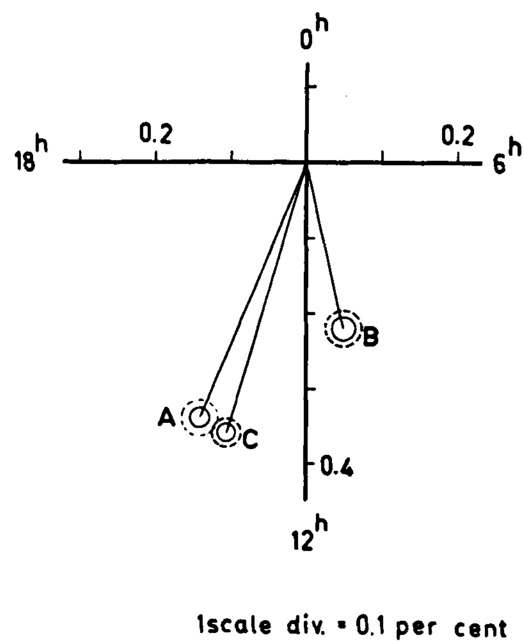

Fig. 8. Phase shifts of the first harmonic of the nucleon component registered at Uppsala. Full circles: standard error from Poisson distribution. Dotted circles: standard error calculated from residuals after fitting first and second harmonics.

A: 31 Aug. 1956—7 March 1957; B: 8 March 1957—20 Jul. 1957; C: 21 Jul. 1957—3 March 1958.

also as if a phase shift had taken place shortly after the start of recording. However, the discussion will be confined to the other two instances when a phase shift appears to have taken place. Accordingly we calculate the means for the periods 10 Oct. 1957—2 Aug. 1958; 3 Aug.—18 Nov. 1958, and 19 Nov. 1958—29 April 1959. The result is illustrated by the clock diagram in Fig. 7. With due regard for standard errors it is evident from this diagram that the phase is the same during the first and third periods. Combining these two periods we find a time of maximum intensity of 1328 GMT ± 17 min. For the period 3 Aug.—18 Nov. 1958 the time of maximum was 1723 GMT ± 31 min. From Fig. 7 it is apparent that the phase shift is real. The phase shift is 56° ± 22°. It is clearly indicated still if we demand a confidence of 95 per cent.

It is possible that the phase shift of the mean daily variation in Uppsala for the two calendar years as compared to the three twelve-monthly periods is due, also, to short periods of a differing phase (Table 1). A study of the details of the vector sum diagram for this station (Fig. 6) reveals the existence of such periods although they are less conspicuous than in the Murchison Bay records. The clock diagram in Fig. 8 illustrates the mean daily variation during the three periods 31 Aug. 1956—7 March 1957; 8 March—20 July 1957, and 21 July 1957—3 March 1958. This case exhibits a striking resemblance to that illustrated in Fig. 7. It is evident that during the middle period the phase differed from that during the two adjacent periods. A phase difference between the two latter is also indicated, the time of maximum being 1327 GMT ± 8 min. for the first one and 1305 GMT ± 8 min. for the third period. During the intervening time, 8 March—20 July 1957, the time of maximum was 1117 GMT ± 16 min. This period with an early maximum falls inside the calendar year 1957. In the following year there does not exist any prolonged period with such a comparatively early maximum (during the sun rotation period no. 1711 the mean time of maximum was 1030 GMT). If the period 8 March—20 July is excluded from the 1957 records the mean time of maximum will be practically the same as that during 1958.

The two vector sum diagrams (Fig. 6) reveal also that the variations of the amplitudes in the two places are not well correlated. This is especially true for the last quarter of 1957 and the first quarter of 1958.

The amplitude of the second harmonic is very small. It is of the same order of magnitude in Uppsala and Murchison Bay (Fig. 3). Both phase and amplitude are severely affected by the exclusion of only a few days. Further, as was shown by the first year's records from the Uppsala monitor, periods exist which have a prominent second harmonic while the amplitude of the first harmonic is of the same order of magnitude or even less (SANDSTRÖM and LINDGREN 1959).

The three consecutive 12-monthly periods combined with the calendar years 1957 and 1958 from the Uppsala monitor provide running means for a study of the second harmonic (Table 2). The vector sum diagram

Table 2.

	Uppsala	Murchison Bay
Geomagn. lat.	58° 36′	75° 30′
Geomagn. long.	107°	137° 30′
Dip	72° 30′	82° 30′
Declination	0° 30′ E	1° 0′ E

for the three 12-monthly periods is to be found in Fig. 5. This diagram as well as the figures in Table 1 strengthen the picture of a considerable variation both in phase and amplitude. If we consider only the Poisson distribution of the number of pulses during the 2-hr intervals the existence of the second harmonic does not seem to be in doubt. If the standard errors are calculated from residuals of the points of measurement after fitting first plus second harmonics the second harmonic appears doubtful (Fig. 3).

The longitude correction

Terrella experiments (MALMFORS 1945, BRUNBERG 1953, BRUNBERG and DATTNER 1953) made it possible to calculate the asymptotic directions of primaries for various rigidities and directions of registration (BRUNBERG 1956). The knowledge thus gathered can be utilized to determine the true direction of the anisotropy responsible for the daily variation (BRUNBERG and DATTNER 1959). However, several obstacles have to be overcome before it becomes possible to determine the correction for the deviation of the primaries in the geomagnetic field with a precision corresponding to that of present day C.R. registrations (DORMAN 1957). Three factors are involved: the rigidity spectrum of the primaries, the solid angle of acceptance of the detector, and the shape of the geomagnetic field. The multiplicity of the nucleon production is a function of the rigidity. It is thus a part of the first one of the three factors listed. The effective rigidity to be ascribed to the primaries of the nucleonic component at the geomagnetic latitude of Uppsala has been discussed elsewhere (SANDSTRÖM and LINDGREN 1959). Concerning Murchison Bay especially favourable conditions govern the angular correction in the east-west plane for particles observed by the monitor in the zenith direction. At this latitude secondaries accepted by the monitor at zenith angles up to 48° originate from primaries having asymptotic directions inside a comparatively narrow cone (ÅSTRÖM 1956; compare also Fig. 32 in BRUNBERG 1956). Under these conditions we have found it permissible to regard the Murchison Bay monitor as observing predominantly in the zenith direction.

The longitude correction ψ and the latitude correction ϕ for the zenith direction and

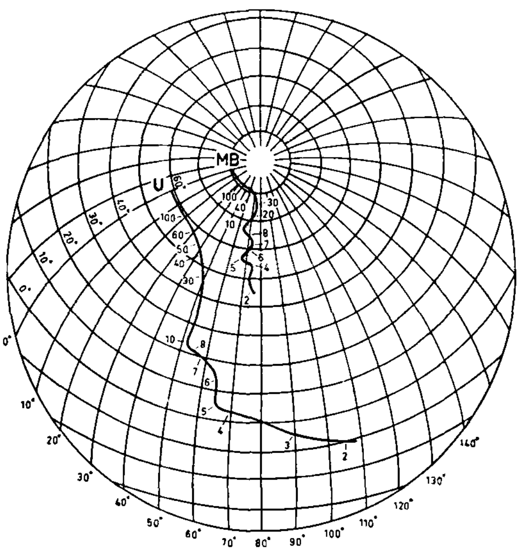

Fig. 9. Longitude and latitude corrections for the zenith directions in Uppsala (U) and Murchison Bay (MB). The rigidities are indicated in the figure. The unit is 10^9 eV/c.

varying rigidities have been plotted in a diagram (Fig. 9) according to BRUNBERG (1956). The values have been recalculated to the geographic lat. 80° (Murchison Bay), Brunberg's original Svalbard values being calculated for geographic lat. 78° (Longyearbyen). In high latitudes a couple of degrees make quite a marked difference. For rigidities below 10 GeV/c the values have been calculated from the measurements by MALMFORS (1945).

The corresponding curve for the zenith direction in Uppsala has been entered into the same figure. The conditions are not as favourable in this case as in the former one. Nevertheless, as has been pointed out by ÅSTRÖM (1956) the spherical representations by BRUNBERG (1956) of ψ and ϕ reveal a certain focussing effect even for latitudes down to 50°. However, the cones limiting the asymptotic directions will not have as small a solid angle as in the case of the Murchison Bay monitor.

What concerns us most is the longitude correction ψ_{MB}. Fig. 9 reveals that for rigidities below 40 GeV/c this correction does not vary very much with the rigidity. Most of the primaries responsible for the nucleonic component will have rigidities below 10 GeV/c. Accordingly it appears to be realistic to put

$$\psi_{MB} = 72° \pm 5° \qquad (1)$$

The most remarkable fact is that even a considerable change in spectral distribution will leave this value unaffected. On the contrary, for Uppsala, the longitude correction will vary strongly with the spectral distribution of the primaries.

The longitude correction was discussed concerning the first year's records from the Uppsala monitor (SANDSTRÖM and LINDGREN 1959). This discussion led to

$$\psi_U = 71° \pm 15° \qquad (2)$$

It is very tempting to try to find a value with smaller limits of error by comparing the curves in Fig. 9. Such a comparison would have to be based on the assumption that above the knee of the latitude effect the rigidity spectrum does not vary with the latitude. Naturally, it has also to be assumed that the direction of the anisotropy is the same regardless of the fact that the Uppsala monitor mainly registers primaries entering the earth's magnetic field parallel or nearly parallel to the equatorial plane while the Murchison Bay monitor registers primaries entering the field in directions 45° to 70° from this plane.

The values in Table 1 show that the phase difference between the two stations varies with the starting point of the 12-monthly periods. On the average it is $12° \pm 5°$. The limits of error are difficult to determine in this case. The variations between the three 12-monthly periods are covered by $\pm 3°$. The standard errors calculated from the residuals after fitting the first plus second harmonics yield $\pm 5°$. The values all refer to 12-monthly means. Such abnormal phase shifts as those illustrated by Figs. 8 and 9 are not considered. The correction for Uppsala calculated from ψ_{MB} and the phase difference between the two stations would then be

$$\psi_U = 84° \pm 10° \qquad (3)$$

Accordingly the curves in Fig. 9 indicate that the "effective" rigidity has to fall between 3 and 5 GeV/c to correspond to the same original direction of the anisotropy in both cases. This is reasonable, considering what is known of the rigidity spectrum of the primaries generating the nucleonic component.

Recent studies of the latitude effect have shown that the actual magnetic field configuration near the surface of the earth has a certain influence on the geomagnetic cut off of C.R. (ROTHWELL 1958, SANDSTRÖM 1958, POMERANTZ, SANDSTRÖM, POTNIS, and ROSE 1959). It has not been proved that there exists a corresponding effect on the trajectories of the primaries. Most of the length of each trajectory will certainly fall in a region where the geomagnetic field is regular and free from anomalies. In Murchison Bay as well as in Uppsala the magnetic meridian plane nearly coincides with the geographic meridian. Dip and geomagnetic coordinates are listed in Table 2.

The direction of the anisotropy

The direction of the observed anisotropy is most conveniently defined through the angle α it makes with the radius vector from the sun. For this angle we have

$$\alpha = \lambda + \tau + \psi \qquad (3)$$

Here λ represents the geographic longitude (Table 3). τ is the difference, in angular measure, between the time of maximum and noon i.e. $\tau = 15^\circ\,(t_{max} - 12)$. The values of τ for the periods under discussion are listed in Table 3. The value of the longitude correction ψ for Murchison Bay is that given by eq. (1). For Uppsala α has been calculated both with a longitude correction according to eq. (2), viz. deduced independently of any comparisons with Murchison Bay, as well as with that according to eq. (3). The results covering the period of recording at Murchison Bay are listed in the last three columns of Table 3, where α_U refers to Uppsala and α_{MB} to Murchison Bay. Naturally, the way of deducing the longitude correction represented by eq. (3) results in nearly coinciding pairs of values in the two last columns of the table. Nevertheless, the direction of the anisotropy as recorded by the Uppsala monitor will still be inside the limits of error asigned to the longitude correction according to eq. (2).

In the discussion concerning the vector sum diagrams in Fig. 6 and the clock diagrams in Figs. 7 and 8 it was remarked that the yearly mean of the daily variation might vary slightly with the starting points of the twelve-monthly periods. This is apparent from the values in Table 3 also. As long as we do not know the reason for the non-periodical phase shifts causing these variations we are not able to eliminate them. Influences from short period variations are probably eliminated to a large extent in every yearly mean (compare final section). Therefore, it should be emphasized that the present discussion on the direction of the anisotropy is concerned only with 12-monthly averages.

A simple way of studying the directions of C.R. anisotropies is to resolve the corresponding vector into components along two axes, one along the radius vector from the sun and one along a tangent to the orbit of the earth (SANDSTRÖM 1956). Concerning the records from Murchison Bay there is no doubt about the existence of the component along the radius vector. It is directed towards the sun. Exactly the same can be said of the Uppsala records if the longitude correction according to eq. (3) is used. A radial component towards the sun is still present when the longitude correction is that given by eq. (2).

The daily variation as a function of the K_p index

Concerning the meson component there exists comparatively strong evidence that the

Table 3.

Period	τ_U	τ_{MB}	α_U		α_{MB}
			$\psi = 71^\circ$	$\psi = 84^\circ$	
1 Sept. 1957—31 Aug. 1958 ...	$14.5^\circ \pm 5^\circ$	$25.0^\circ \pm 5^\circ$	$103^\circ \pm 20^\circ$	$116^\circ \pm 15^\circ$	$115^\circ \pm 10^\circ$
Calendar year 1958	$22.3^\circ \pm 5^\circ$	$37.7^\circ \pm 5^\circ$	$111^\circ \pm 20^\circ$	$124^\circ \pm 15^\circ$	$128^\circ \pm 10^\circ$
1 May 1958—30 Apr. 1959 ..	$22.3^\circ \pm 5^\circ$	$33.5^\circ \pm 5^\circ$	$111^\circ \pm 20^\circ$	$124^\circ \pm 15^\circ$	$124^\circ \pm 10^\circ$

phase of the daily variation depends on the prevailing geomagnetic conditions (SEKIDO and KODAMA 1952, SANDSTRÖM 1955). For a similar treatment of the present data on the nucleonic component the days were divided into five classes determined by the maximum K_p index of each day (SANDSTRÖM 1955). These classes are

$$\text{I}: [K_p]_{\max} \leq 1^+$$

$$\text{II}: 1^+ < [K_p]_{\max} \leq 3^+$$

$$\text{III}: 3^+ < [K_p]_{\max} \leq 5^+$$

$$\text{IV}: 5^+ < [K_p]_{\max} \leq 7^+$$

$$\text{V}: 7^+ < [K_p]_{\max} \leq 9^\circ$$

For the sake of comparison between Uppsala and Murchison Bay one of the periods was selected so as to include the whole set of neutron monitor records from the latter place. As the records from Uppsala show good agreement in phase as well as in amplitude for the three 12-month periods illustrated by the vector sum diagram in Fig. 5 it was considered appropriate to combine these three periods into one.

A study of this kind has already been published concerning the first year of the Uppsala records (SANDSTRÖM and LINDGREN 1959). As regards the days employed in the comparison between Uppsala and Murchison Bay those belonging to class I are exactly the same in both cases. In classes II and III the number of days is so big as to make the few cases of odd days completely insignificant. Concerning class IV the available number of days is anyhow so low as to necessitate the employment of as many days as possible for the sake of the statistical fluctuations. Moreover, variations correlated with the geomagnetic conditions might be responsible for some of the day to day phase shifts which undoubtedly exist. From this point of view it appears desirable to accumulate as many days as possible for each K_p index class. If the number of days in one group is as large as 60 the removal of a few days does not affect either amplitude or phase in a serious way (SANDSTRÖM and LINDGREN 1959).

Concerning the most disturbed days (class V) we encounter another problem. These days are usually those on which a prominent Forbush decrease occurred. An ordinary linear trend correction is then often inadequate for the separation of the true daily variation from the singular event (SANDSTRÖM and LINDGREN 1959). Therefore, no vector corresponding to class V has been included in the clock diagrams of Figs. 10 and 11. However, in the Uppsala records there is a sufficient number of days available during which C.R. conditions were undisturbed despite the very high K_p indices. These days have been employed for a special study illustrated in Fig. 12.

Concerning Murchison Bay (Fig. 10) the vectors for all four classes of days fall together inside the limits of error. Also the contemporary Uppsala records display small variations, the class I days excepted. Despite the

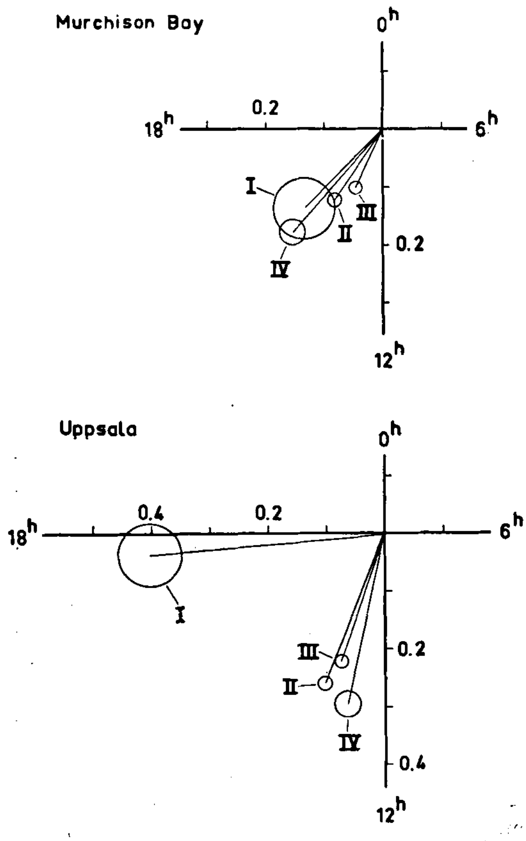

Fig. 10. The mean first harmonics for days divided into classes according to their maximum K_p index. Period: 26 Aug. 1957 to 30 Apr. 1959. The Roman numbers mark the grouping of days according to the classification on p. 341.

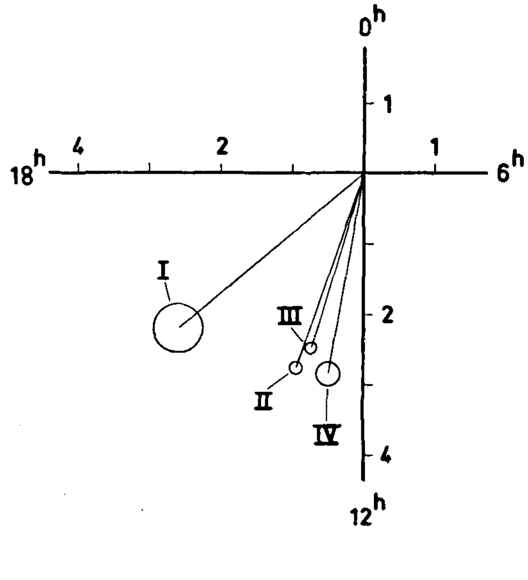

Fig. 11. The mean first harmonics at Uppsala for days divided into classes according to their maximum K_p index. Period of 36 months: 1 Sep. 1956 to 31 Aug. 1959. The Roman numbers mark the grouping of days according to the classification on p. 341.

small number of days the limits of error are sufficiently narrow to prove the reality of the phase shift for quiet days (class I). Likewise there is little doubt that on class IV days the maximum tends to appear earlier than on the days of classes II and III. Space forbids the introduction into Figs. 10 and 11 of the standard errors based on the residuals of the experimental points after fitting the first plus second harmonics.

During the period 31 Aug. 1956—31 Aug. 1957 the phase of the class I days in Uppsala was the same as that of classes II and III. The introduction of accurately calculated limits of error does not change this aspect. The phase shift for the class I days from this period to the following 12-month period is more than twice the standard errors calculated from the Poisson distribution. From this point of view it is perhaps not suitable to found an analysis on as long a period as 36 months. But, this special shift excepted, the changes from one year to another are small. A period over several years will present, through better statistics, a more accurate determination of the phase shifts between the other classes of days. From Fig. 11 can be seen that the class IV days certainly have an earlier mean time of maximum than days with $[K_p]_{max} \leq 5^+$. In all the three clock diagrams (Figs. 10 and 11) the phase appears to be nearly the same for classes II and III.

The long period of 36 months has also yielded a sufficient number of days with $7^+ < < [K_p]_{max} \leq 9^\circ$ for the study illustrated in Fig. 12. In this case we have found it important to calculate also the limits of error from the residuals after fitting the first and second harmonics. They are illustrated by dotted circles in Fig. 12. During the whole period 11 days of class V were found which did not have any single event disturbing the normal variation. The 2-hr values for each single day can be read from the curves in columns 1, 2, and 4 in the upper part of Fig. 12. To these 11 days can be added six days with small Forbush decreases or parts of such decreases (curves in column 3, Fig. 12). The corresponding vectors are to be found in the clock diagram in the lower part of the same figure. In the first case the phase is nearly the same as for the class IV days in Fig. 11. In the second case it lags 22° behind (1.5 hrs). The amplitude has also increased. If all available days of class V are employed the phase lag increases to 27° and the mean amplitude becomes twice that of the group of 11 days first considered. As the added days are such with prominent Forbush decreases it is evidently the decreases and not a change in the normal daily variation which produce the big amplitude.

The change in phase is not as easily brought back to the same source. Nevertheless, days with $[K_p]_{max} > 7^+$ but undisturbed by actual decreases (11 d vector in Fig. 12) have nearly the same phase and amplitude as those belonging to class IV.

The variation of the amplitude with $[K_p]_{max}$ differs from that observed for the meson component (SANDSTRÖM 1955). At present the nucleon component has its biggest amplitude on days with $[K_p]_{max} \leq 1^+$. It decreases with increasing $[K_p]_{max}$ until $[K_p]_{max} = 5^+$. After that it appears to increase slightly (class IV). The same picture is offered by all the three clock diagrams (Figs. 10 and 11).

From the small spread of the vectors for the nucleonic component at Murchison Bay it follows that the direction of the anisotropy outside the earth's magnetic field depends only slightly on the disturbances causing the variations of the K_p index. The same can be said about the Uppsala values, days with $[K_p]_{max} \leq \leq 1^+$ excepted. Concerning the latter the Uppsala records (Fig. 11) indicate a late time of maximum. Correcting for the deviation of the primaries by the earth's magnetic field we find the direction of the anisotropy to be $174° \pm 20°$ to the evening side for $\psi_U = 71°$ (eq. 2) and $187° \pm 15°$ for $\psi_U = 84°$ (eq. 3). A comparison with the contemporary measurements from Murchison Bay makes both these values look meaningless. Resolving the anisotropy into radial and tangential components we find that at the latitude of Uppsala the latter would be either non-existent or smaller than that at Murchison Bay. If the correction according to eq. 3 is accepted it would even be possible that it had the opposite direction. At the same time the radial component would have a very much bigger amplitude at Uppsala than at Murchison Bay. Even considering the very wide limits of error of the longitude correction this seems contradictory.

If instead, the first year of the Uppsala records (SANDSTRÖM and LINDGREN 1959) is studied, the picture will be different. The same is to some extent true also of the whole 36-month period. In the first case the vector for the class I days has almost the same direction as that for the period unresolved according to the K_p index. In the second case the angles of direction will be $139° \pm 20°$ for $\psi_U = 71°$ and $152° \pm 15°$ for $\psi_U = 84°$. This appears at least more reasonable. But the erratic phase shifts still call for a special study.

During the period 26 Aug. 1957 to 30 Apr. 1959 the records contain only 12 days belonging to class I. The very big amplitude of the first harmonic at Uppsala indicates that it might be possible to study the daily variation on single days. The vector sum diagrams in Fig. 13

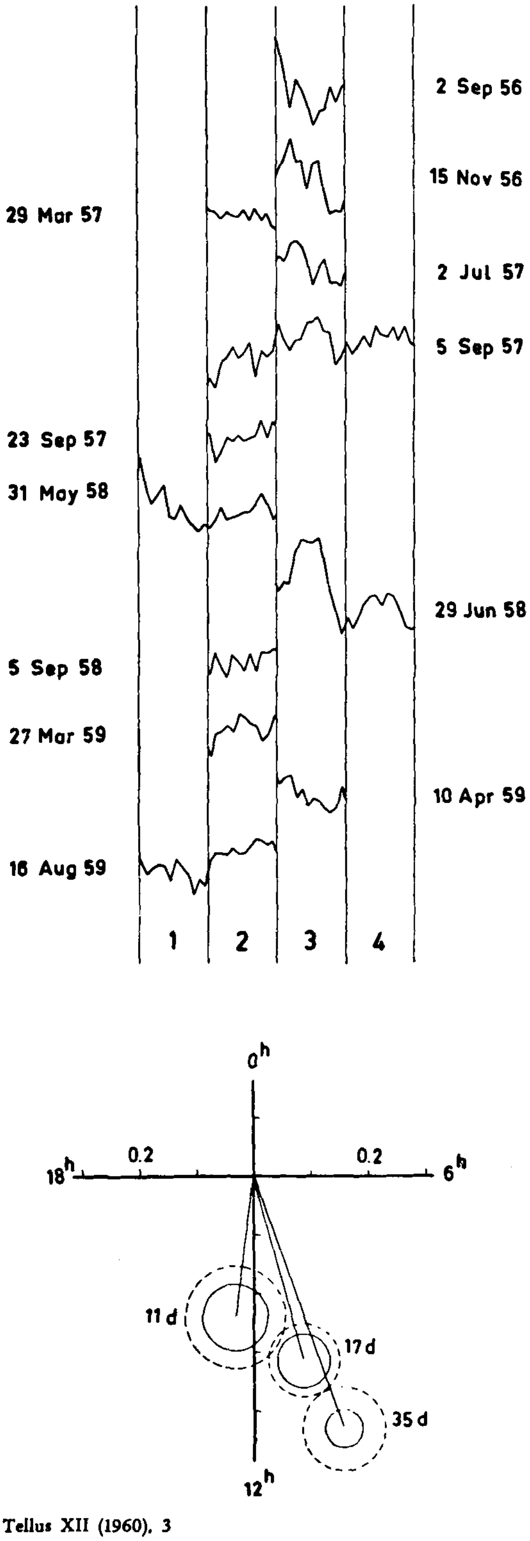

Fig. 12. Mean daily variation for days with $[K_p]_{max} > 7^+$. The vector marked 11 days represents the days illustrated by the curves in columns 1, 2, and 4. The vector marked 17 days shows phase and amplitude when those days are added which are illustrated by the curves in column 3. The third vector (35 days) represents the mean of all available days with $[K_p]_{max} > 7^+$. The curves in the upper part show the variation in relative intensity for each day.

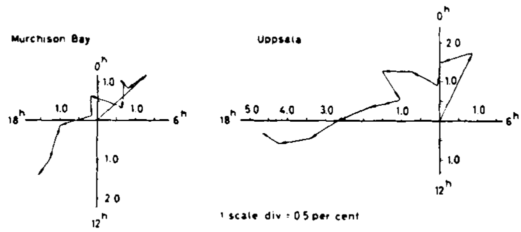

Fig. 13. Vector sum diagrams for the first harmonics of single days with $[K_p]_{max} \leq 1^+$. From the origin the vectors represent 23 and 28 Dec. 1957, 24 May, 13 Sep., 12 Oct., 5, 6, and 30 Nov., 1 Dec. 1958, 1 and 21 Jan., and 22 Apr. 1959.

are the result of such a study. It is interesting to note that on the first one of the 12 days under discussion the phase of the first harmonic differs considerably from the mean of the whole class of days. Because of the unavoidably big standard errors the phases are not significantly different at Murchison Bay and Uppsala. However, the removal of this particular day has a remarkable effect on the means for the remaining 11 days (Fig. 14). At Murchison Bay the phase remains the same while the amplitude increases by a factor of approximately two. At Uppsala the phase decreases. In this case, too, the amplitude increases. In Fig. 14 the dotted vectors represent the means of the original 12 days, while the full drawn vectors represent the means of the remaining 11 days.

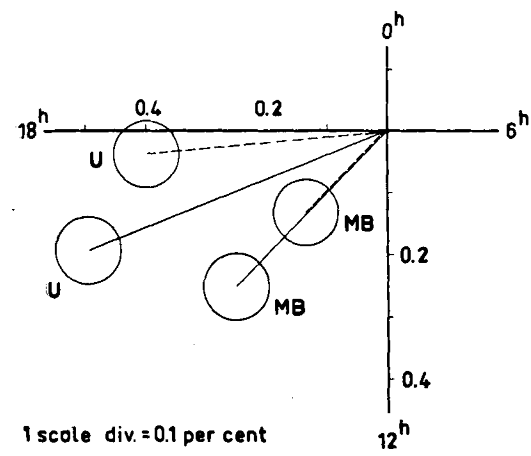

Fig. 14. Diagram showing amplitude and phase of the first harmonic for the class I days at Uppsala (U) and Murchison Bay (MB). Dotted vectors: all days with $[K_p]_{max} \leq 1^+$ included. Full drawn vectors: the same days exclusive 23 Dec. 1957.

A comparison between Figs. 10 and 14 reveals that the exclusion of 23 Dec. 1957 does not bring the Uppsala and Murchison Bay vectors of the class I days into phase inside the standard errors as calculated from the Poisson distribution. However, the results indicate that 12 days is too short a period for the elimination of disturbances in the daily variation not correlated with the phenomena characterized by the K_p indices.

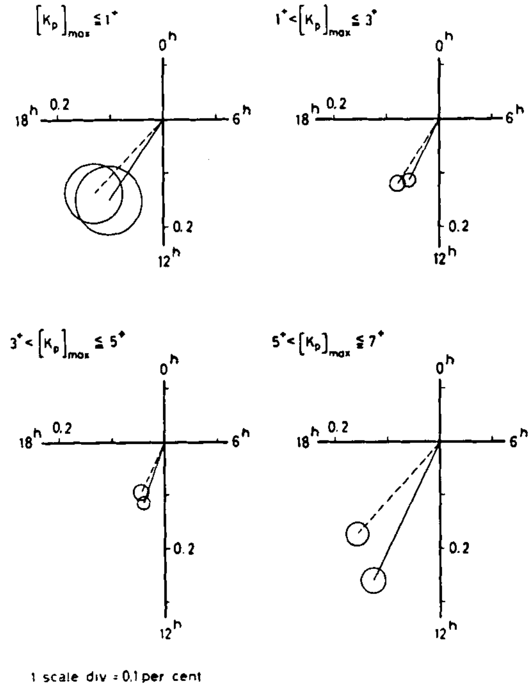

Fig. 15. Clock diagrams for the mean daily variation at Murchison Bay showing the phase shifts for the first four classes of days when the period 3 Aug. to 18 Nov. 1958 is being removed (full drawn vectors).

It ought to be observed that 23 Dec. 1957 is at the end of the recovery period after a Forbush decrease (compare SANDSTRÖM and LINDGREN 1959).

It is of some interest to study how the removal of the period 3 Aug. to 18 Nov. 1958 affects the phases and amplitudes of classes I—IV. This period had a phase which differed markedly from the phase during the rest of the Murchison Bay records (Figs. 6 and 7). In the case of Uppsala the phase change as well as the change of amplitude is negligible. For Murchison Bay the shifts are significant through their consistency although they are relatively small in comparison with the limits of error. As can be seen from Fig. 15 the shifts are in the same direction in all four cases. The direction is that expected from the removal of the period with abnormal phase. The results indicate also that the late time of maximum is unconnected with the geomagnetic conditions during the period in question.

Although the amplitude of the second harmonic is very small in comparison with the limits of error there is no doubt of its existence especially for days with $[K_p]_{max} > 3^+$. However, for the geomagnetically most disturbed days ($7^+ < [K_p]_{max} \leq 9^\circ$) the mean amplitude does exceed the limits of error.

The first year's records from the Uppsala monitor reveal a significant amplitude of the second harmonic for days belonging to class IV (Sandström and Lindgren 1959). However, for the whole period of 36 months the mean amplitude for this class is insignificant. Disregarding those cases where the amplitude is less than the limits of error no variation in phase can be observed. This might be due, partly, to the inaccuracy caused by the small amplitudes.

Concluding remarks and summary

Undoubtedly there is a considerable day to day variation both in phase and amplitude. They have been commented upon by Firor et al. (1954), and by Mc Cracken (unpublished thesis 1959). It is possible that some of these variations are due to local effects. In other cases, for instance 28 June 1958 (Fig. 12) it is doubtful whether the big amplitude is to be ascribed to the normal daily variation or to some superimposed single event. Under these circumstances the mean value over a long period becomes important not only as a means of reducing the influence of statistical fluctuations. If, as most of the evidence indicates, the main component of the daily variation can be regarded as being due to a particle wind blowing along the earth's orbit, the tilting of the axis of rotation of the earth will possibly give rise to a small seasonal variation in the amplitude. This seasonal variation will disappear in the yearly mean. A sideral component with constant amplitude will also disappear in the yearly mean. Should the amplitude not be constant it would still be diminished to a minimum through the process of averaging.

Dattner and Venkatesan (1959) have listed seven possible components of the diurnal variation. The existence of these components has been derived from the theory by Alfvén (1954) concerning the origin of cosmic rays. One of these components is identical with the solar time variation which is the main subject of the present investigation. According to Dattner and Venkatesan most of the other components should more or less cancel one another in an annual average. This also indicates the yearly mean as a less complicated object of study than short period means. Nevertheless, as is shown by the Murchison Bay and Uppsala records, the yearly means can be affected by non-recurrent periods with a differing phase (Figs. 7 and 8). If only they were contemporary the existence of such periods could be explained by the appearance or disappearance of one or two of the components listed by Dattner and Venkatesan. As in this case non-contemporary phase shifts occur at two stations on the same meridian it appears as if an explanation through such components is invalidated. A recent investigation has led Parsons (1960) to suggest that at least part of these phase shifts are due to a universal time component of limited durability.

When means for periods as short as one month or 27 days are being studied it is necessary to bear in mind that the day to day variability will play a prominent part. This fact might be responsible also for the phase shifts revealed by the vector sum diagrams in Fig. 6.

A period of 20 months has been employed for the correlation of the phase and amplitude variations with $[K_p]_{max}$. It could be argued that in this case, too, 12-month periods would offer a better elimination of the influence from certain variable components. However, such an elimination becomes possible only when nearly all the days of the 12 month periods can be employed. It might also be partly successful if an evenly distributed number of days is employed. Neither is possible for days sorted into classes according to their $[K_p]_{max}$ values. Therefore it is necessary to allow for certain disturbing influences. These will not be serious for classes II and III, which contain the majority of days. As has already been shown such influences might be considerable where days of class I are concerned. The results presented here can be summarized as follows:

The harmonic analysis of the Uppsala and Murchison Bay records shows the amplitude of the yearly mean daily variation of the nucleonic component to be bigger at the former place than at the latter. The quotient between the two amplitudes is in full accordance with the assumption that the direction of the anisotropy is parallel to or nearly parallel to the orbital plane of the earth.

The Murchison Bay records reveal that the anisotropy makes an angle of more than 90° with the radius vector from the sun. Therefore, if resolved in one tangential and one radial component the mean yearly anisotropy will have a radial component directed towards the sun.

Making it a condition that the direction of the anisotropy should be the same when calculated from the Uppsala records as when calculated from the Murchison Bay records, a longitude correction can be found for Uppsala.

During three consecutive years the Uppsala records reveal only minor changes in the phase and amplitude of the yearly mean first harmonic.

When short periods are analyzed phase shifts are found which do not appear simultaneously in the records from the two stations.

At Murchison Bay the first harmonic exhibits a small negative phase shift with increasing values of $[K_p]_{max}$. At Uppsala the first harmonic displays clearly the same small phase shift, days with $[K_p]_{max} \leq 1^+$ excepted. In this latter case the phase is sometimes strongly shifted towards late hours, and the amplitude increases considerably. In one case this has been shown to be due to one single day with strongly differing phase and amplitude. This day had the same phase and amplitude in Uppsala and Murchison Bay but affected the means for the two stations in different ways.

The amplitude of the second harmonic is very small. The phase of the second harmonic varies considerably from one year to another.

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