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SIDEREAL ANISOTROPY OF HIGH ENERGY COSMIC RAYS NEAR THE EQUATOR+

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SUMMARY: An experiment detecting extensive air showers responding to primary energies greater than 10^{14}ev is being conducted at Chacaltaya (Elevation 5210 meters; geographic latitude 16^{o}S) with coincidences between counter trays separated at least by 20 meters. Some evidence of the sidereal anisotropy of the order of 1% with the time of maximum at 1600 L. S. T. is found although the variation cannot be discussed with the absorption curve of the extensive air showers.

INTRODUCTION

The rotation of the earth may cause any cosmic ray measuring

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instrument to show a variation, as it points to different directions in space. A study over the past few years by instruments responding to primaries of low and medium energies has shown a significant variation of intensity with solar time, while over a sidereal day the intensity appears to be almost constant. This fact has been generally interpreted that the solar variation arises partly due to the terrestrial changes following the solar time and partly due to different electro-magnetic structure in the interplanetary space in different directions. The high degree of isotropy in sidereal time could then be due to large scattering of primaries while passing through the magnetic fields in the interplanetary space, so that they lose completely their correlation with their original directions. This would suggest that if the anisotropic distribution of primary cosmic radiation in our galaxy exists, it could only be detected by measuring high energy cosmic rays which would be slightly affected by the magnetic fields in the earth's neighbourhood. A study of the sidereal time variation is thus related to the search for the galactic anisotropy in the primary cosmic radiation. A great interest was therefore centered in the study of extensive air showers which respond to primaries with their energies greater than 10^{14}ev.

In the energy range from 10^{14} to 10^{15} ev measurements done in the northern hemisphere by Hodson[1] indicated an amplitude of 1.15 ± ± 0.61% with maximum at 2330 L.S.T. while Daudin and Daudin[2] whose measurements were more precise reported various but all negligible amplitudes suggesting that it would be always difficult to separate it from the atmospheric effects. With the energies about 10^{16} ev Cranshaw and Galbraith[3] first found an amplitude of 4.9 ± 1.5% with maximum at 1030 L.S.T., but their later results are in contradiction with the earlier ones so that the total data do not show any significant variation. This removes the discrepancy that appeared between the earlier results of both Daudin and Daudin[2] and Cranshaw and Galbraith, both experiments being conducted at the same latitude.

In the Southern hemisphere, Farley and Storey[4] in the beginning reported an amplitude of 1.5 $\pm$ 0.23% with maximum at 1700 L.S.T. However, their later results also failed to confirm the earlier ones thus indicating negligible sidereal variation. Recent report by Chapman and Ryder[5] shows a variation of 0.88 $\pm$ 0.65% with maximum at 1700 L.S.T. which also can not be said to be significant.

In 1956, however, it appeared that the results of Hodson, Daudin and Daudin and Farley and Storey, show the maximum intensity within half an hour of the passage overhead of the galactic plane. The galactic center being 23°S, any anisotropy bearing relation with the galactic center is expected to show up more favourably in the observations in the southern hemisphere. In addition, most of the above mentioned experiments were conducted at sea level. It is somewhat advantageous to conduct these experiments at high altitudes in order to have large counting rate to improve the statistical significance of the data.

In view of these facts an experiment was planned in 1956 and set up in Chacaltaya (Geomagnetic Latitude 4°S, Geographic latitude 16°S and Longitude 68°W) which is located at 5210 meters elevation with a mean annual pressure of 397 mm. of mercury. This station has an additional advantage that being situated near the equator the seasonal temperature changes are quite small compared to those intermediate latitudes.

The purpose of this paper is to give a first account of the sidereal variation in high energy primaries observed at Chacaltaya over the last 18 months[6] of which approximately 230 days were used.

EXPERIMENTAL ARRANGEMENT

The equipment consists of 4 trays of GM counters placed in a horizontal plane, as shown in figure 1. Trays I, II and III consist of 8 counters each, while tray IV has only two counters. All counters were 1" in diameter and 22" in length with brass walls 0.02" thick and were filled with a mixture of petroleum ether and argon (composition ratio 1:10) at a total pressure of 8.4 cm. The counters in each tray were connected in parallel making the sensitive area 1135 cm^2 for each of the first three trays and 284 cm^2 for the fourth one.

Plus 1000 V. were supplied to the anodes of each tray through 1 meg. ohm. resistance, while the cathode of each counter was connected to a separate potentiometer which allowed to vary its potential from 150 V to 0, thus enabling the observer to adjust separately the operating voltages of individual counters without disturbing the normal operation of the equipment.

Tray II and III were housed in the main laboratory building where temperature changes from 17^o to 22^o, while the other two trays were placed outside in thermally insulated boxes whose inside temperature was controlled thermostatically.

Above the first two trays there was an absorbing material of 3 gms/cm^2 while the last two had negligible absorbing material over them and were placed on the mountain side with a slope of 28^o. The trays were in a horizontal position.

Counter pulses from the trays were brought to a central room through coaxial cables and fed to a blocking oscillator which in turn triggered a fast quencher feeding back to the counter trays. The output of the blocking oscillator was also fed to a coincidence circuit which registered triple coincidences between trays I, II and III and four fold coincidences separately. The resolving time of the coincidence circuit was less than 3 μs. The single tray rates of the first three trays were of the order of 7.200 counts per minute, the three-fold coincidences give about 340 counts per hour. The accidental coincidences for the three-fold were of the order of three per hour and of the fourfold coincidences 0.04 per hour. Each coincidence output was registered by two separate recorders, one of which self cleared every hour; in addition, the counting rates of trays I and II were monitored continuously. All the mechanical recorders were photographed every hour together with two altimeters, a thermometer indicating the temperature of the central room and a 24 hour electric clock which was driven by a frequency standard together with the timer which triggered the camera control circuit every hour.

Counting rates of all the trays were checked five times a week while a quick check of the whole equipment was done from the hourly rates of triple and four-fold coincidences. The operating points of each counter were checked every second day and if necessary were adjusted. Approximately once a month a general check of the operating condition of the equipment was conducted. In the beginning the failures of main power shut down the whole equipment requiring manual restart. Unfortunately, there were frequent power cuts on Saturdays which stopped the equipment until Monday, thus losing three days in a week. Later on, an automatic reset mechanism was provided which reconnected the unit permitting time to heat the filaments.

SELECTION OF THE DATA

It was found that there were occasional increases in the counting rate of two monitored trays. It was further noted that in the majority of cases these increases were simultaneous in both trays. Although trays III and IV were not monitored it could be supposed that only on very rare occasions increases in counting rate occured in these trays without affecting the monitored units and thus remained undetected. Apparently these increases were due to oscillations in the quenching circuits. A further check was provided by the analysis of the individual counting rates taken five times a week. The data for such hours when such increases were observed were rejected. Days when the operating level of the counters was adjusted were also eliminated. Although the data was read every hour, only two hourly intensities were used to facilitate computation. This also permitted the use of the instantaneous pressure values at the hours where the intensity was centered.

DISCUSSION

Figure 2 shows the uncorrected variation of threefold and fourfold coincidences as well as the corresponding pressure plotted against L.S.T. The pressure is expressed as the heights given by altimeter and their values could be converted to cm. by the following relation 3280 ft. = 5.4 cm. which was obtained from the slope of the height-pressure curve at a height of 5200 meters given by Montgomery. It could be realised from Fig. 2 that there exists a very good correlation between C. R. variation and pressure variation. The harmonic components of these variations are expressed on harmonic dials in Fig. 3 and Table I. Considering the phases of these components C. R. and pressure vectors are very well correlated, but there does not exist a unique relation between them from the two harmonics separately. If the second harmonic of C. R. arises due to that of pressure only the first harmonic of pressure is too small to account for that of C. R. vector. On the other hand if the first harmonic of C. R. is supposed to arise completely due to that of the pressure, there will be a large residual second harmonic whose cause could be rather difficult to ascertain. Hence the normal method of least squares fit which assumes that one curve completely arises from the other will not be truly applicable in this case. On the other hand, there is not any known cause except semidiurnal oscillations of pressure which can give rise to such a large semidiurnal component in C.R. but the first harmonic can arise due to the temperature effect. We therefore assume that the second harmonic in variation of threefold and fourfold coincidences arises because of that of pressure between which the correlation is greater than 0.96 and the pressure coefficients thus determined are as follows:

For 3-fold coincidences	11.05 ± 2.38% per cm. Hg.
For 4-fold coincidences	7.08 ± 3.96% per cm. Hg.

By the least squares method the following coefficients were obtained:

For 3-fold coincidences	10.75 ± 2.85% per cm. Hg.
For 4-fold coincidences	7.95 ± 3.70% per cm. Hg.

which are also in agreement with the previous ones. Considering the experimental errors our results are consistent with those found by other workers[2,3,4]. However, from the experimental absorption curve given by Greisen[7] to which our fourfold coincidence geometry would correspond, we expect 15% reduction pressure coefficient of the fourfold coincidence variation. Although experimental errors may not allow to confirm this fact the nature of the curves given in Fig. 2 showing an extremely good correlation between pressure and cosmic ray intensity gives a strong indication that a low coefficient observed in the fourfold coincidence variation may have a genuine significance.

With the coefficients obtained by the first method the data of both threefold and fourfold coincidences were corrected for pressure effects.

Sidereal variation.- Since the intensities were averaged over two hour intervals, it was impossible to convert the data on sidereal time every day. Hence the monthly averages corrected for pressure were shifted by two hours every month starting from September, so as to obtain every month data in terms of local standard sidereal time. This procedure smoothed the sidereal variation whose final value could be obtained by the method suggested by Chapman and Bartels[8].

Fig. 4 shows the sidereal variation of threefold and fourfold coincidences obtained by this procedure.

Since all the fourfold coincidences are registered as three folds there also exists the contribution of Fig. 4 (b) in Fig. 4(a). This contribution could be estimated by multiplying the later curve by 0.29 (which is the ratio of the hourly counting ratio of fourfold to threefold coincidences). A dotted curve in Fig. 4(a) shows the remaining variation after removing the contribution of the fourfold. It will now be realized that sidereal variation of the showers given only threefold coincidences is extremely small and hence could be considered as isotropic. We have therefore concentrated our attention to the fourfold variation only in further investigation on the sidereal time.

The solar component may have a seasonal modulation. This together with the incomplete meteorological correction may give rise to an apparent sidereal variation when analysis is conducted by the above procedure. In order to correct for these effects Farley and Storey[4] have described a method suggested by Cocconi to make an estimate of them on antisidereal time which is to have 364 days in a year. We have calculated the contribution of these effects and the corrected curve is also given in Fig. 4(b).

The harmonic coefficients corrected for the smoothing and the seasonal variation give an amplitude of 1.05 ± 0.25% and time of maximum 15.8 ± 1.0 L.S.T. for the first harmonic and an amplitude of 0.61 ± 0.25% with time of maximum 0.1 ± 0.8 L.S.T. for the second harmonic.

We wish to point out that our results are barely significant and would appear not to be in complete agreement with the recent reports of the other workers, except for the fact that the sidereal anisotropy is not in excess of 1%. The time of maximum of the first harmonic at about 1600 L.S.T. together with the large second harmonic would be quite consistent with the interpretations of Davis[9] where he suggests the sidereal anisotropy arising both by the acceleration of cosmic rays by Fermi mechanism and by the inhomogeneities in cosmic ray densities normal to the field lines. However, the mean energy of the showers recorded by the threefold coincidences (5×10^{14}ev) is not very different from that of the showers of the fourfold coincidences (2×10^{15}ev), and it would be difficult to tie up a sidereal variation in fourfold coincidences with negligible variation in the threefold coincidences. Our results should therefore be considered as suggestive only.

This experiment together with a new set up to record very high energy of the primary spectrum (expected to be in operation within a short period) is being persued and we expect to report new results shortly.

CONCLUSION

The barometric coefficient of the extensive air showers at an altitude of 5210 meters near the equator was found to be 11.05 ±2.38 per cm. of mercury and 7.08 ± 3.96 per cm. of mercury for two different set ups responding to primary energies of 5 x 10^{14} ev and 2 x 10^{15} ev respectively. The later coefficient is suggestive of a small value than that found for those energies at intermediate latitude and at sea level.

In the energy range near about 10^{15} ev there appears to be a sidereal variation of about 1% with maximum at about 1600 L.S.T.

ACKNOWLEDGEMENTS

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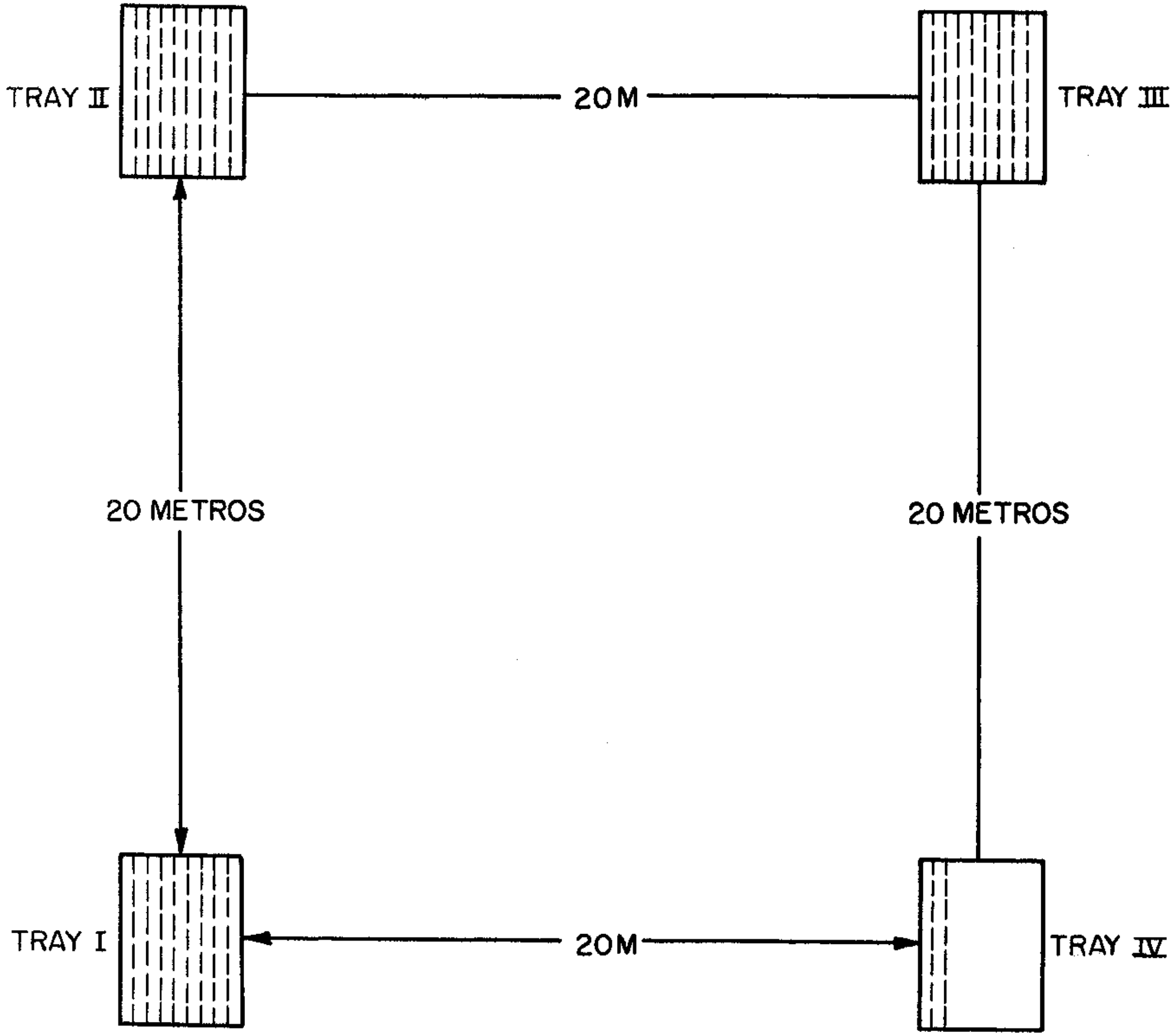
TABLE I

First and Second Harmonic Coefficients of 3-fold, 4-fold coincidences and the corresponding pressure variation on solar time.

	FIRST HARMONIC		SECOND HARMONIC	
	Amplitude	Angle of Maximum	Amplitude	Angle of Maximum
3-fold Coincidences	0.38%	– 78°	0.51%	+ 137°
4-fold Coincidences	0.34%	– 86°	0.34%	+ 129°
Pressure for 3-fold	4.5 ft.	* – 43°	28.5 ft.	147°
Pressure for 4-fold	8.0 ft.	– 46°	29.7 ft.	140°



EXPERIMENTAL ARRANGEMENT

FIG. 1

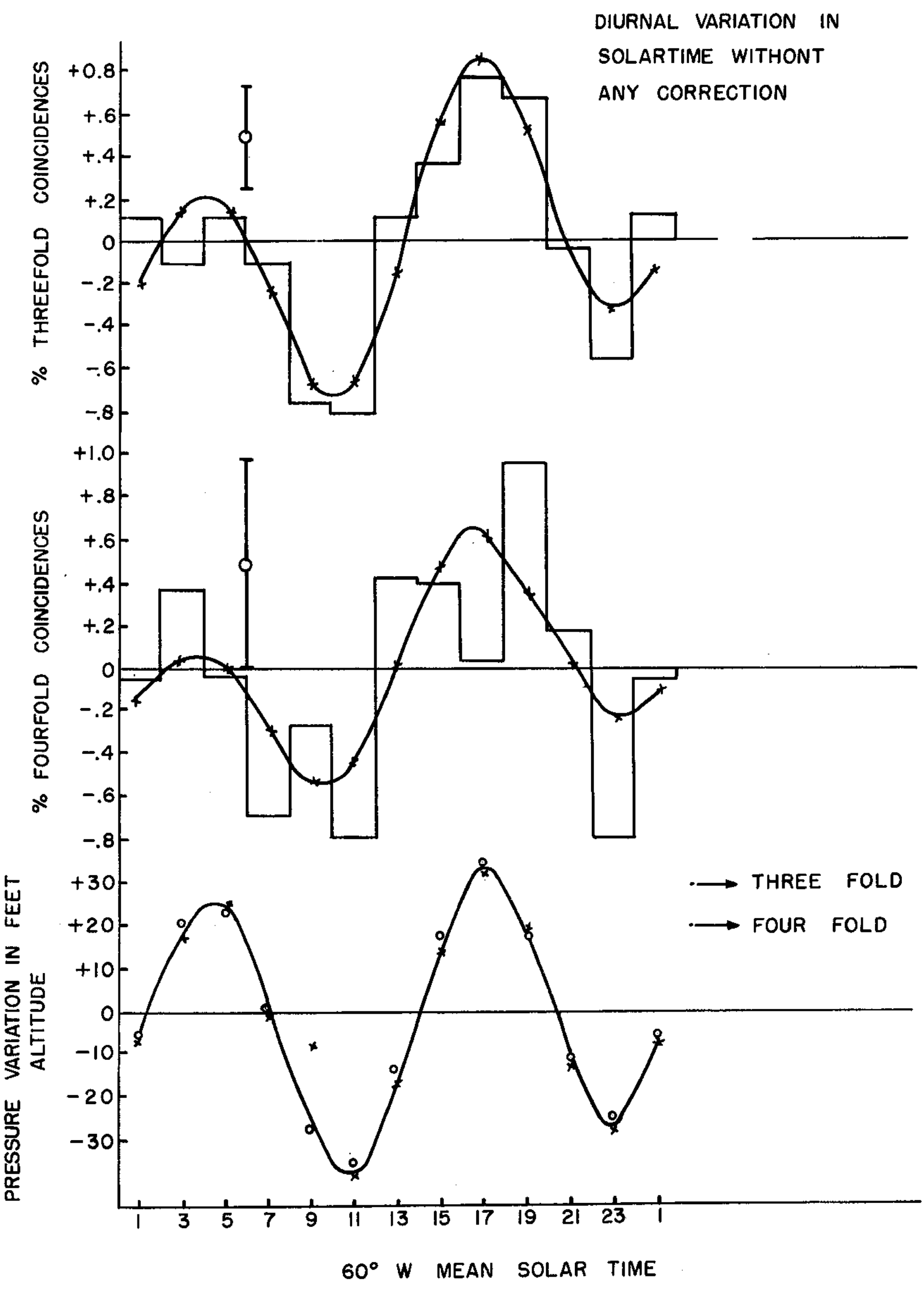
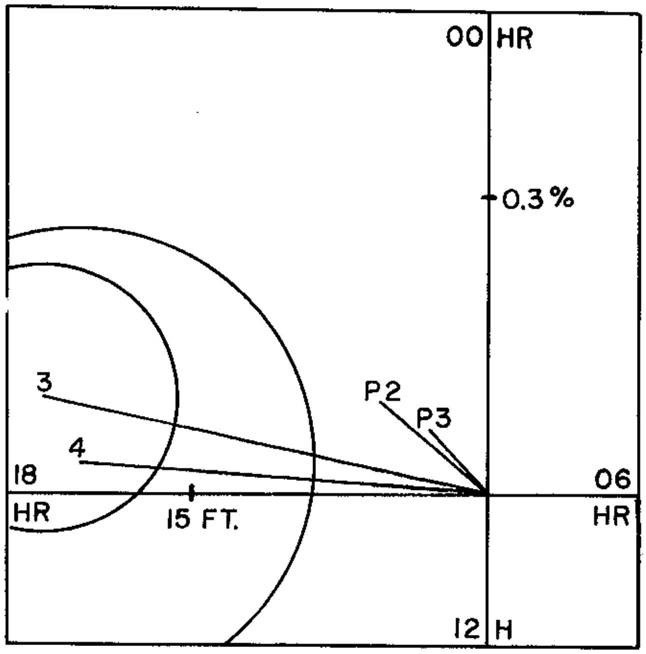
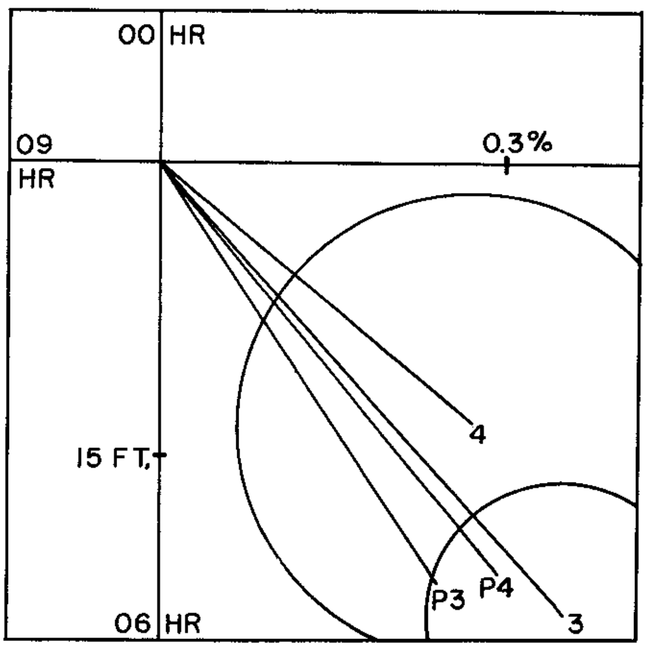

DIURNAL VARIATION IN SOLARTIME WITHONT ANY CORRECTION
% THREEFOLD COINCIDENCES
+0.8
+.6
+.4
+.2
0
-.2
-.4
-.6
-.8
% FOURFOLD COINCIDENCES
+1.0
+.8
+.6
+.4
+.2
0
-.2
-.4
-.6
-.8
PRESSURE VARIATION IN FEET ALTITUDE
+30
+20
+10
0
-10
-20
-30
THREE FOLD
FOUR FOLD
1
3
5
7
9
11
13
15
17
19
21
23
1
60° W MEAN SOLAR TIME

FIG. 2



1st HARMONIC VECTORS

FIG. 3

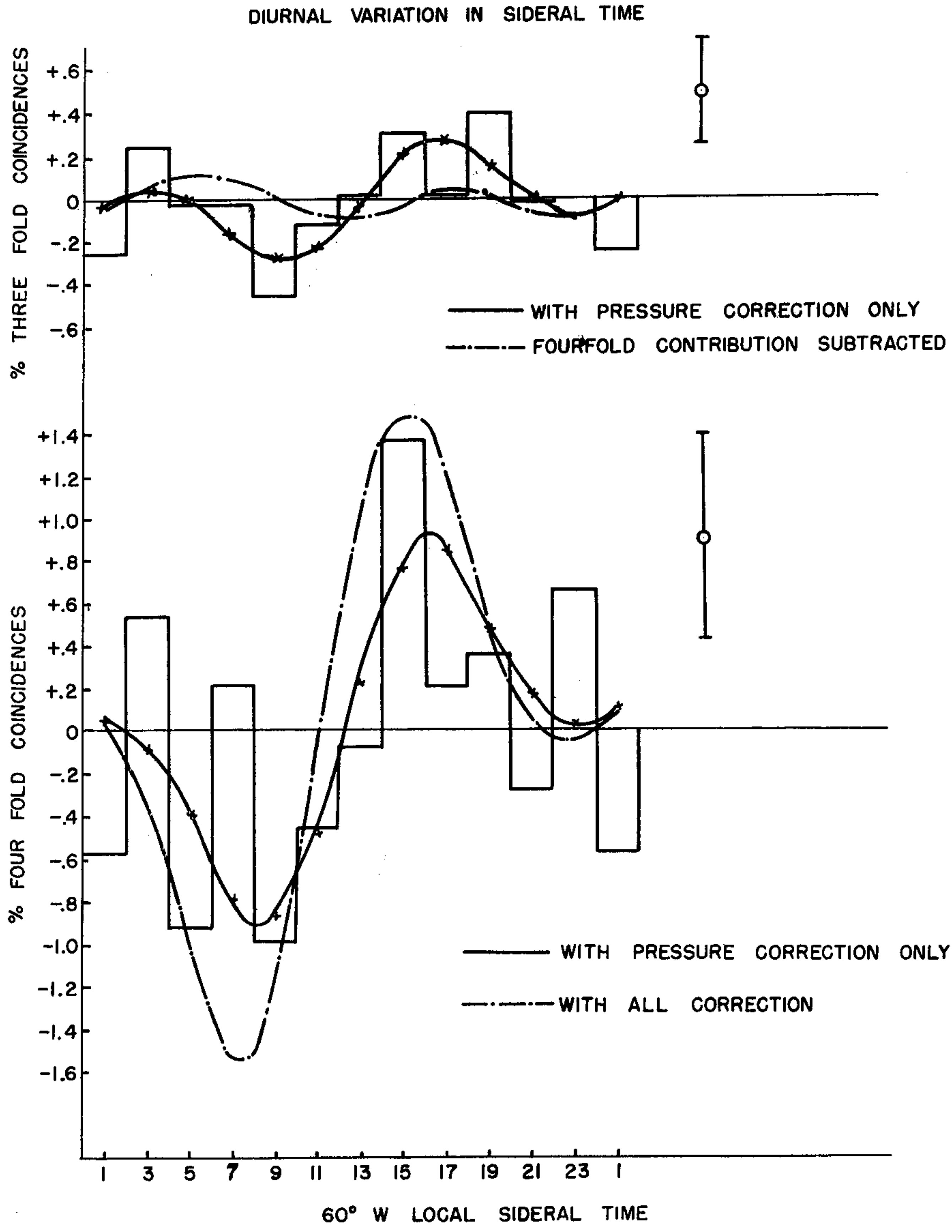


2and HARMONIC VECTORS

P_2 P_3 PRESSURE VECTORS

3, 4 COINCIDENCE VECTORS

60° WEST MEAN SOLAR TIME HARMONIC DIALS



DIURNAL VARIATION IN SIDERAL TIME
% THREE FOLD COINCIDENCES
+.6
+.4
+.2
0
-.2
-.4
-.6
WITH PRESSURE CORRECTION ONLY
FOURFOLD CONTRIBUTION SUBTRACTED
% FOUR FOLD COINCIDENCES
+1.4
+1.2
+1.0
+.8
+.6
+.4
+.2
0
-.2
-.4
-.6
-.8
-1.0
-1.2
-1.4
-1.6
WITH PRESSURE CORRECTION ONLY
WITH ALL CORRECTION
1 3 5 7 9 11 13 15 17 19 21 23 1
60° W LOCAL SIDERAL TIME

FIG. 4