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GEOMAGNETIC MICROPULSATIONS, pi2, AT LOW LATITUDES

DAVID ORR
Department of Physics, University of York, England

and

HANS G. BARSCZUS
Centre de Geophysique, ORSTOM, M'Bour, Senegal

Abstract—Pi2 micropulsations observed at two widely separated, low-latitude stations; M'Bour, Senegal in West Africa and Makerere, Uganda in East Africa have been compared. The frequency of occurrence of pi2 events for 1966 has been observed at both stations and the relative amplitudes of clear events computed, together with the characteristics of the horizontal magnetic components at M'Bour and the horizontal Earth current characteristics at Makerere.

The observed similar frequency of occurrence pattern at the two stations is discussed in relation to five factors which effect the detection of micropulsations; (1) the relative distribution of amplitudes amongst the 3 components of the disturbance changes with time and decreases the chance of identifying an event towards the dawn and dusk meridians. (2) The position of the pi2 source relative to the observer. A study of the relative amplitudes at Makerere and M'Bour appear to support a theoretical model which postulates the source fixed with respect to the Sun on the midnight meridian. (3) The effect of damping on the transmission of micropulsations through the ionosphere. (4) The dispersion of the signal and (5) the signal to noise ratio.

1. INTRODUCTION

Irregular, damped pulsations, classified as pi2, by Jacobs *et al.* (1964) have been studied by several workers. Review papers have been published by Jacobs and Westphal (1964) and by Troitskaya (1967). Two of the main conclusions are that pi2 are observed most clearly at night with maximum frequency of occurrence usually a little before midnight, local time, and that the amplitude of an event is latitude dependent, the maximum amplitude occurring in the auroral zone. Also most authors, for example Herron and Heirtzler (1966), conclude that the dominant pi2 period does not change with latitude.

Makerere, Uganda has geographic co-ordinates 0·5°N, 32·5°E and the magnetic latitude from the survey of Whitham and Hoge (1961) is 12·6°S. M'Bour, Senegal has geographic co-ordinates 14·4°N, 17°W and magnetic latitude 7·8°N. These two stations are thus separated by almost 50° in longitude.

2. INSTRUMENTATION

The Makerere data was obtained from the East–West channel of an Earth current system; lead electrodes separated by 730 m were connected by means of insulated cables to a high resistance in series with a sensitive galvanometer. The movement of the galvanometer mirror is monitored by a Sefram spot-follower recorder. A potential difference of 1 mV at the electrodes gave a 10 mm deflection on the paper chart. The response curve was essentially flat for periods equal to or greater than 10 sec. Further details are given in Orr (1966) and Shelton (1966).

At M'Bour the magnetic field was measured using an induction coil wound on a mu-metal core, connected to a Kipp galvanometer working as a fluxmeter. A light spot from an external source deflected from the galvanometer mirror was recorded by a Kipp camera on photographic paper at a speed of 6 mm/min. This system was described by

Selzer (1957). For a period of 60 sec, this arrangement had a sensitivity of 0·19 gammas/mm for H and of 0·13 gammas/mm for D.

3. OBSERVATIONS

3.1 *Pi2 frequency of occurrence*

The daily variation of occurrence of pi2 pulsations at Makerere (Orr, 1966) and those at M'Bour (Barsczus, 1966) both give a peak at close to local midnight. It is clear that these observations, made at ground level at stations separated by 49·5° in longitude, which both give a peak in frequency of occurrence close to local midnight are showing that their global distribution is strongly influenced by local time. The shape of the frequency of occurrence histograms such as Figs. 1 and 2 depend, to some extent, on the sensitivity and selectivity of the detecting equipment. In compiling pi2 statistics criteria are laid down for deciding which groups of micropulsations are called events. For example one imposes conditions with regard to period, the duration of the event, the degree of damping and the signal to noise ratio. Therefore different detecting equipment at the same site could give somewhat

FIG. 1. DAILY VARIATION OF OCCURRENCES OF pi2 PULSATIONS AT MAKERERE FOR 1966.

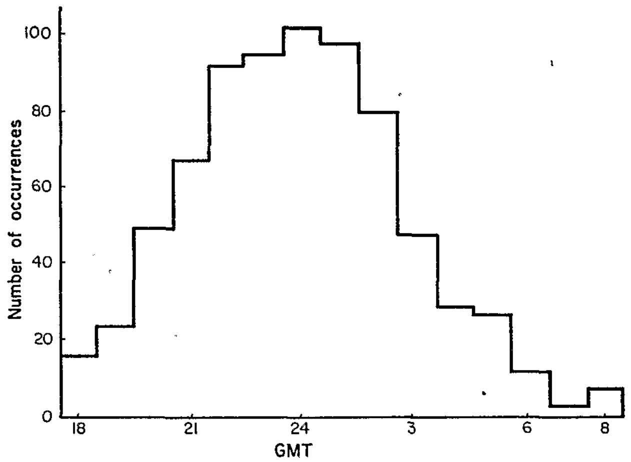

FIG. 2. DAILY VARIATION OF OCCURRENCE OF pi2 PULSATIONS AT M'BOUR FOR 1966.

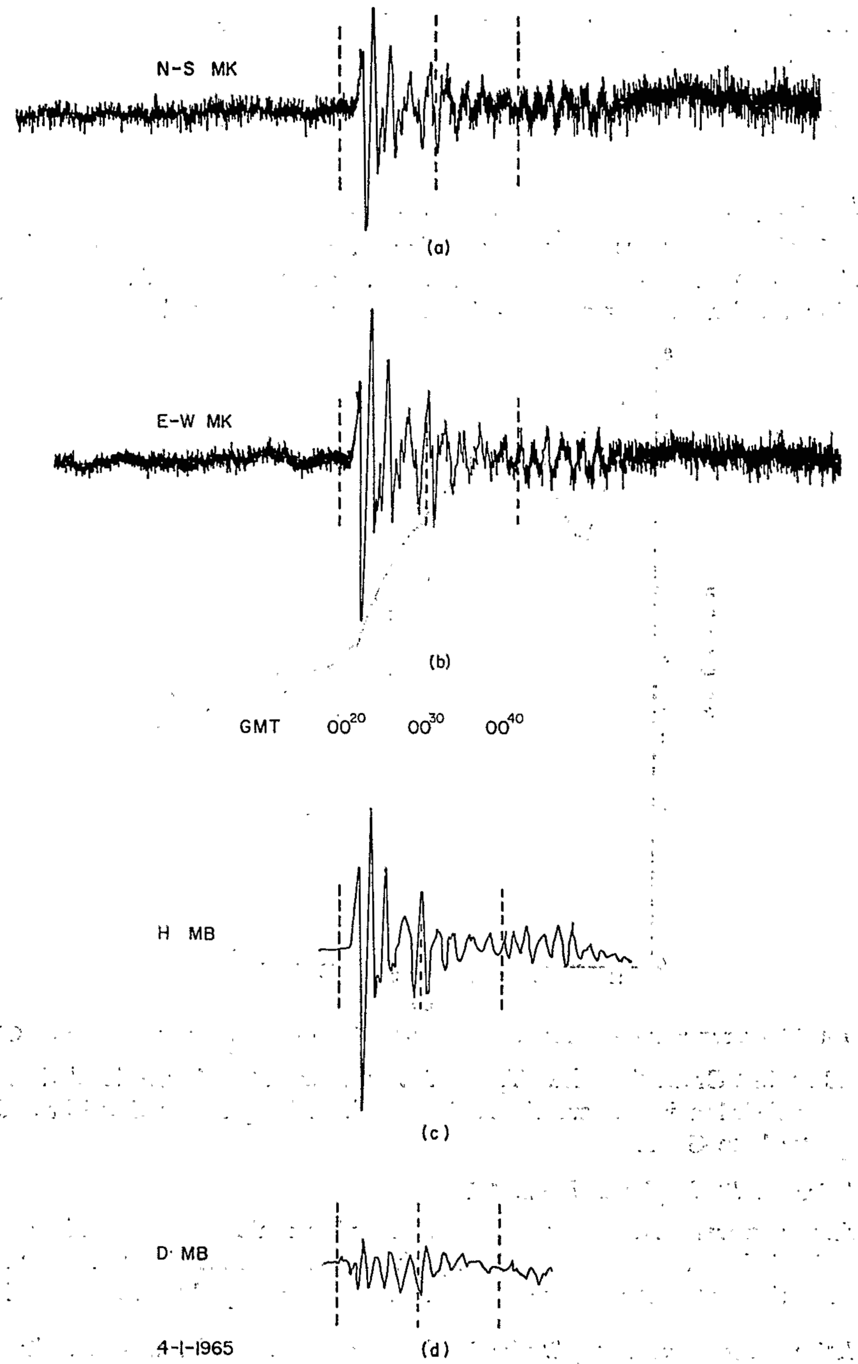

FIG. 3. Pi2 EVENT OCCURRING AT 0022 hr GMT ON 4th JANUARY 1965.
(a) Makerere North–South Earth current
(b) Makerere East–West Earth current
(c) M'Bour North–South magnetic
(d) M'Bour East–West magnetic.

different statistics. However, researchers from all continents seem to agree that pi2 events occur most frequently at close to local midnight.

It was found that clear pi2 events on the magnetic North–South records at M'Bour were usually identifiable at Makerere on the East–West Earth current records. In a majority of cases the waveform at the two places was remarkably similar. An example is given in Fig. 3.

3.2 *Relative amplitudes of events at M'Bour and Makerere*

For 157 clear events occurring between September 1964 and December 1966 average ratios of peak to peak amplitudes at the two stations were computed. The results are shown in Fig. 4 in the form Makerere East–West Earth current amplitude divided by M'Bour

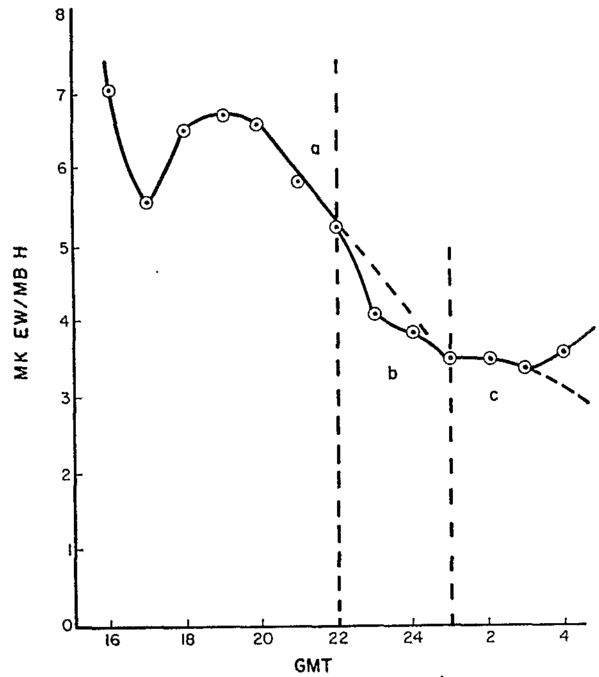

FIG. 4. MAKERERE EAST–WEST AMPLITUDE/M'BOUR NORTH–SOUTH AMPLITUDE AGAINST GMT.

H plotted against Greenwich Mean Time. The M'Bour and Makerere local times, corresponding to their longitudes, are obtained approximately by subtracting 1 hr and adding 2 hr respectively to GMT.

3.3 *Relative amplitude of* H *and* D *at M'Bour*

During the hours immediately before and after local midnight the maximum peak to peak amplitude in *H* is at least 3 times the peak to peak amplitude in *D*. Nearer the dawn and dusk meridians the *D* component becomes more nearly equal to *H* as shown in Fig. 5.

3.4 *Relative Earth current amplitudes in the North–South and East–West directions at Makerere*

The average ratio of the amplitudes changes by a factor of about 2 during the night as shown in Fig. 6. The East–West channel having maximum amplitudes around midnight and minimum amplitudes at about 1900 hr and 0500 hr LT.

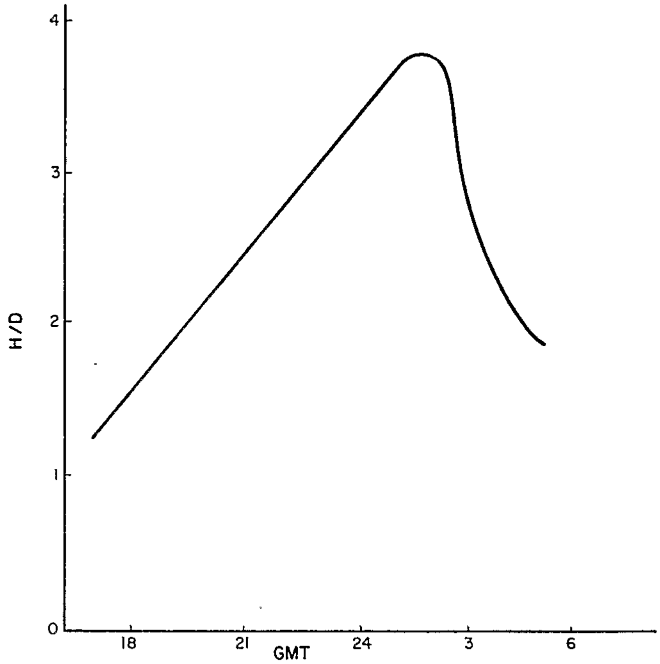

FIG. 5. M'BOUR H/D AGAINST GMT.

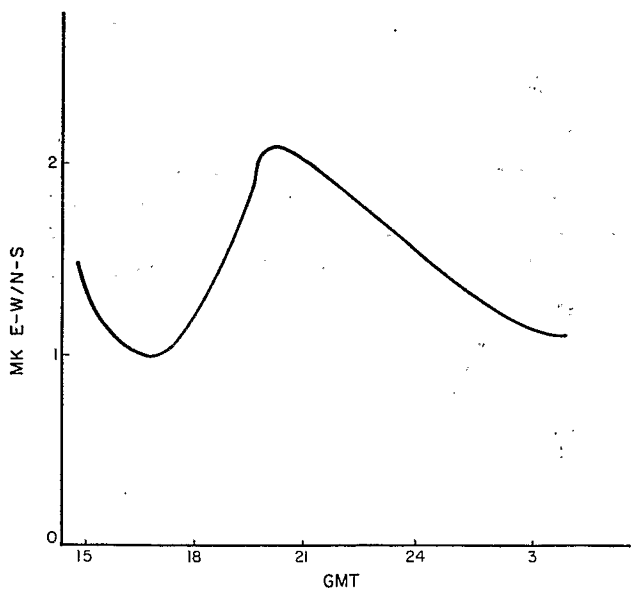

FIG. 6. MAKERERE E–W/N–S EARTH CURRENT AMPLITUDES AGAINST GMT.

3.5 *The initial sign of* D *relative to* H *at M'Bour*

The initial sign of *D* relative to the initial sign of *H* was noted for 103 pi2 events. The initial movement of *H* in a clear pi2 event at M'Bour is invariably upwards signifying an increase in *H*. An upward movement of *D* indicates that the Westward declination has increased. The results are presented in the form of the percentage of events where the *H* and *D* traces both showed an initial upward movement plotted against GMT, Fig. 7. Figure 7 shows that between 1900 and 2400 GMT the components occur out of phase most frequently. While before 1900 hr and after 2400 hr the *H* and *D* components are more likely to be in phase.

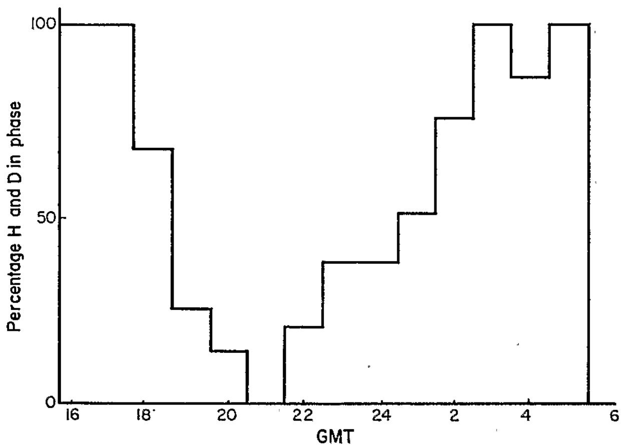

FIG. 7. THE PERCENTAGE OF pi2 EVENTS AT M'BOUR WHERE THE INITIAL DISPLACEMENT OF *H* AND *D* ARE IN THE SAME DIRECTION AGAINST GMT.

3.6 *Damping of pi2 events*

A damping coefficient was obtained for each event. This was evaluated by measuring the maximum peak to peak amplitude and the next two successive peak to peak amplitudes. Each measured throw was divided by the succeeding one and an average coefficient formed for each event. The damping coefficients were grouped and averaged over each hour giving the variation with time shown in Fig. 8 for Makerere.

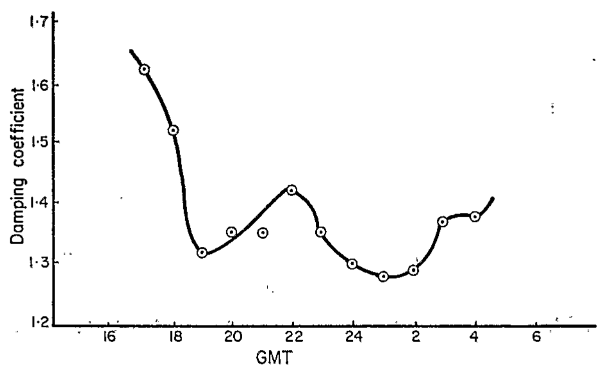

FIG. 8. THE VARIATION OF THE DAMPING COEFFICIENT AT MAKERERE AGAINST GMT.

4. DISCUSSION

4.1 *Introduction*

In this section we discuss and seek to interpret the observation, summarized in Figs. 1 and 2, that low-latitude pi2 occur most frequently just before local midnight during quiet Sun years. Whether pi2 micropulsations are detected and recognized as an event at ground based stations depends on at least five factors;

(1) The relative distribution of amplitudes amongst the three components of the disturbance.

(2) The position of the pi2 source relative to the receiving station.

(3) The distribution and amount of ionization associated with the path taken by the waves between the source of the oscillation and the receiver.

(4) The dispersion of the signal.

(5) The magnitude and frequency distribution of signals from other sources detected at the same time.

4.2 *The relative amplitudes of the three components of pi2 events*

The Z magnetic component at M'Bour was always very small: the vertical Earth current at Makerere was not measured. The H component is almost invariably dominant over D at M'Bour as is shown in Fig. 5. At Makerere the E–W Earth current signal was usually greater in amplitude than the corresponding North–South amplitude. The variation of relative amplitudes with GMT is shown in Fig. 6. Clearly, a particular pi2 event occurring during the early evening or in the early morning will not appear so distinctively as an event near to midnight because the energy in the dawn and dusk events is being shared approximately equally between the two components instead of appearing dominantly in the North–South magnetic component.

4.3 *The position of the pi2 source relative to the receiving station*

There are several strands of evidence which make it tempting to suggest that the source of pi2 events is on the nightside of the magnetosphere, preferentially occurring close to the midnight meridian, and located at an altitude greater than or equal to about 7 Earth radii.

Saito and Matsushita (1968) have summarized the differences between bay disturbances and pi2 and concluded that pi2 cannot be explained simply as fluctuations of the ionospheric currents that are responsible for bay disturbances. They draw attention to the possible mechanism of particles incident on the gap between the closed magnetosphere and the Northern and Southern magnetospheric tails inducing an almost poloidal oscillation.

The observations that pi2 events are detected most frequently at close to local midnight and are almost linearly polarized in the North–South direction for the magnetic components are both indicative of a source which is preferentially located close to the midnight meridian. The similarity of waveform of pi2 at conjugate stations (Jacobs and Wright, 1965; Wright and Lokken, 1965) and the variation with latitude having maximum amplitude in the auroral zones and the reversal of sign of the amplitude on the pole side of the auroral zone all suggest that the phenomenon is linked with the field lines which connect the auroral zones.

One can further support the thesis that the pi2 source is located near the midnight meridian from the relative amplitude data given in Fig. 4. The change in the relative amplitudes of Makerere E–W signals to M'Bour H from 1900 to 0300 hr GMT is the type of variation to be expected from a source fixed in universal time which has a longitude-dependent attenuation factor. That is an attenuation factor dependent on the distance from the meridian on which the pi2 source is situated.

The simplest theoretical model for the variation of amplitude of a pi2 event with longitude would assume a source located on the 2400 hr meridian, say, and the amplitudes measured at ground stations at adjacent meridians dropping of linearly as indicated in Fig. 9. Stations separated by 45°, in longitude, as they rotate under the pi2 source, assumed

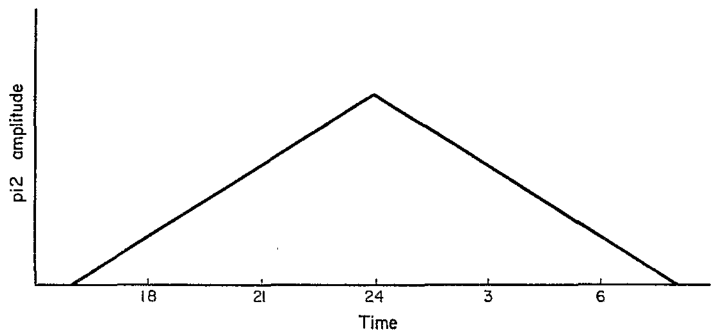

FIG. 9. Pi2 AMPLITUDE AGAINST TIME.

fixed on the Earth–Sun line, would give rise to a relative amplitude curve with the time as shown in Fig. 10. The 45° (or 3 hr) separation approximates to the Makerere-M'Bour situation. This curve is seen to be composed of 3 distinct portions: portion *a* corresponding to both stations on the dusk side of the source, portion *b* corresponding to approximately equal signals at the two stations and portion *c* represents the situation when both stations are on the dawn side of the source. On this model there is a discontinuous change in the gradient of the relative amplitude curve at 2400 hr and 0300 hr. On the experimental

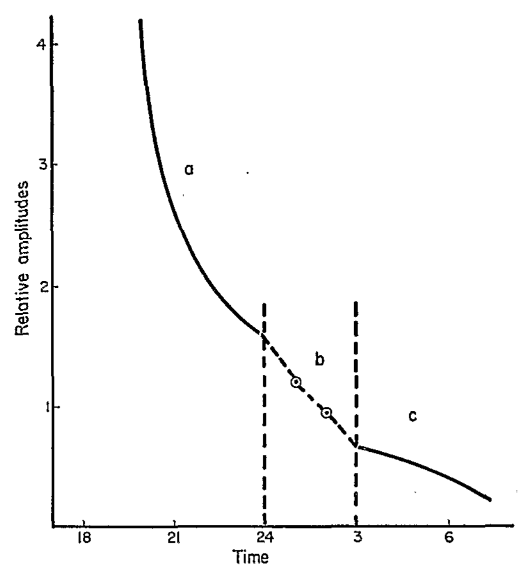

FIG. 10. THE RATIO OF AMPLITUDE OF pi2 SIGNALS RECEIVED AT TWO STATIONS SEPARATED BY 45° IN LONGITUDE AGAINST TIME WHEN THE pi2 SIGNAL STRENGTH VARIES AS SHOWN IN FIG. 9.

relative amplitude curve, Fig. 4, there is a strong suggestion of a discontinuity at 2200 hr GMT and a discontinuity in the gradient at 0100 hr. This implies that the source of pi2 micropulsations was usually located on the midnight meridian in 1966.

The differences in the experimental curve, Fig. 4 and the prediction of the simple theoretical model, Fig. 10 before 1900 hr and after 0300 hr GMT can be explained by noting that pi2 events are not linearly polarized as assumed in the model but the pi2 energy is shared between the 2 horizontal components. When the Makerere East–West/North–South amplitude against time curve, Fig. 6, is divided by the M'Bour H/D values a curve of the same type as Fig. 10 emerges having minima at 1700 and 0200 hr and a maximum at 2000 hr.

4.4 *The distribution and amount of ionization between pi2 source and ground based receiving station*

In this section we note some of the properties of the night-time ionosphere close to Makerere and discuss possible effects of the ionosphere on the transmission of micropulsations.

Field and Greifinger (1966) have considered the equatorial transmission of geomagnetic micropulsations through the ionosphere and lower exosphere. The transmission coefficients shows no resonant peaks or any appreciable attenuation in the pi2 period range during the night for the particular model ionosphere and exosphere chosen. They showed that at low altitudes where the equation for the electric field, E in the hydromagnetic mode was given by

$$\left[\frac{d^2}{dZ^2} + \frac{i\omega}{V_A{}^2}\frac{\nu_i}{1+\dfrac{\nu_e\nu_i}{|\omega_e\omega_i|}}\right] E \simeq 0$$

where the positive Z direction is vertically downward, ω is the wave angular frequency, ν_i, ν_e are the ion-neutral and electron-neutral collision frequencies respectively, V_A is the Alfvén speed, ω_i, ω_e are the ion angular cyclotron and electron angular cyclotron frequencies respectively.

The second term in the above equation, which is essentially the square of the index of refraction, is purely imaginary. Thus, in the region where ion and electron collisions with neutral particles are important the micropulsations are damped. The amount of attenuation suffered by micropulsations propagating from an exospheric source will depend both on the distribution and the amount of ionization between the source and the receiver. If we assume a scale height for the collision frequencies of 10 km then for a micropulsation of period 60 sec the above equation is valid for altitudes below 200 km. A study of the Nairobi ionospheric data for 1966, obtained from the World Data Centre at Slough, reveals that there are very few hours of the night when there are significant amounts of ionization below 200 km in the F-region. The amount of damping due to the F-region is therefore assumed to be small. Nairobi is the nearest ionospheric station to Makerere; it is some 500 km to the East and on a very similar latitude: on average, the Makerere ionosphere is likely to be similar to the ionosphere at Nairobi, there being a time lag of about 17 min.

The ionization most likely to cause attenuation of pi2 at Makerere at night arises from sporadic-E. In order to get an estimate of the amount of ionization, and therefore the attenuation, the average monthly values of f_0E_s for each hour were added. The total is plotted against time in Fig. 11. This shows that the attenuation of hydromagnetic waves due to sporadic-E at Makerere might be expected to be rather constant between 1900 and 0300 hr GMT (i.e. 2100–0500 hr LT, the attenuation increasing outside this time interval. This correlates with the variation of the damping coefficient at Makerere Fig. 8 for the time before 1900 hr and after 0300 hr GMT. However, the damping coefficient is a parameter which should be interpreted with caution. It is a measure of two things; (1) the amount of damping in the system and (2) the amount of dispersion suffered by the pi2.

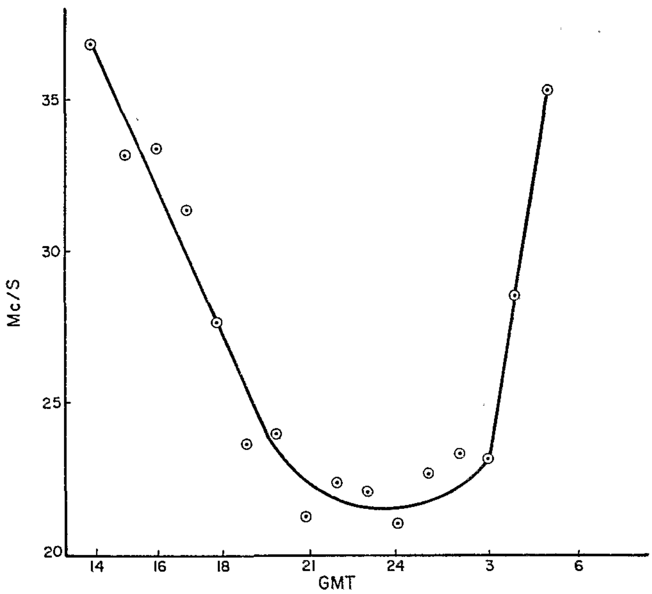

FIG. 11. THE SUM OF THE MONTHLY f_0E_s AVERAGES FOR THE YEAR 1966 AT NAIROBI AGAINST GMT.

For example, an event which appears as highly impulsive, peaking on the first throw on a magnetogram recorded on the midnight meridian sometimes appears as a small amplitude wavepacket on the dawn meridian. The dawn event would give a low value for the damping coefficient even though the overall energy recorded had been severely attenuated. The maximum appearing in the damping coefficient at local midnight at Makerere may be explained by dispersion and will be discussed in a future report.

4.5 *The dispersion of pi2 signals*

Pi2 events exhibit a variety of waveforms: from highly impulsive events which have their maximum amplitude on the first or second excursion of the recording spot and then decay exponentially to those which have a wavepacket appearance growing gradually to their peak amplitude and then decaying equally smoothly. If dispersion effects exist between the stations this will be made apparent by a change in waveform in recordings made at the two stations. A simple test was applied: for events recorded at both stations the number of oscillations to reach the maximum amplitude was noted. In 72 per cent of the events the wavepattern peaked on the same oscillation; this was interpreted as evidence for small dispersion. Where there are differences in the waveform there is a tendency (21 per cent of events) for the observatory which is closer to the midnight meridian to peak on an earlier throw rather than on a later one (7 per cent of events).

The number of clear pi2 events recorded at both stations before 2000 hr GMT drops off quite markedly: at this time the Makerere records show many clear pi2 while the M'Bour charts indicate a severely attenuated and dispersed waveform which is often recorded in the Orstom magnetic bulletins as a trace of pc4. Similarly, after 0500 hr GMT, when M'Bour is still in darkness and it is just after dawn at Makerere, very few pi2 are recorded at Makerere even though quite clear events are visible at M'Bour. The reasons for not recording the event at Makerere are usually threefold: attenuation and dispersion of the signal and the event is usually seen against the daytime background of comparable amplitude pc3 or pc4, activity.

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