IC/86/309
INTERNAL REPORT
(Limited distribution)

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

# ANOMALOUS SHORT PERIOD GEOMAGNETIC VARIATIONS AT TWO STATIONS IN SRI LANKA *

K. Kunaratnam **
International Centre for Theoretical Physics, Trieste, Italy.

MIRAMARE - TRIESTE
August 1986

* To be submitted for publication.

** Permanent address: Department of Physics, University of Jaffna, Jaffna, Sri Lanka.

Abstract An analysis of the rates of change in the geomagnetic field components in the period range 20 – 600 sec recorded at Kondavil and Hikkaduwa, two stations in the equatorial electrojet belt near the nothern and south western coasts respectively of Sri Lanka, shows anomalous variations. The results confirm induced current concentration in the Palk Strait and deflection of induced currents round the southern coast of Sri Lanka postulated by earlier workers from observations of SSC and Bay events at Indian stations and from analogue and numerical model studies. At Kondavil, which is situated close to the geomagnetic equator, no appreciable difference in the night-time and day-time values of $\Delta Z/\Delta H$ and $\Delta D/\Delta H$ ratios was noticed while at Hikkaduwa, a station situated under the edge of the equatorial electrojet belt, a day-time enhancement of $\Delta Z/\Delta H$ ratios was found at all periods in the observed range. An enhancement of the H component at Colombo over that at Hikkaduwa was also found at short periods, the enhancement being greater at day-time. The day-time enhancement in the $\Delta Z/\Delta H$ ratios at Hikkaduwa and in the ratio of the H components at Colombo and Hikkaduwa could be due to the effect of the equatorial electrojet on the short period variations.

## 1. Introduction

Anomalies in transient geomagnetic variations such as Bays, SSCs and Substorms have been observed at three permanent Indian magnetic observatories, Trivandrum, Annamalainagar and Kodaikanal, which are in the equatorial electrojet belt. Of these, the first two are in the coastal region and the anomalies there have been the subject of intensive study by several workers (Nitiyananda et al., 1977; Rajaram et al., 1979; Srivastava and Abbas, 1980; Singh et al., 1982). Similar anomalies have been observed at a number of temporary stations in the South Indian coastal region( Thakur et al.,1981). It has been shown(e.g. Nitiyananda et al.,1977) that the anomalies at Annamalainagar and Trivandrum cannot be explained on the usual coast effect. Regionally induced currents channelled through a conducting region in the lower crust or upper mantle under the Palk Strait and deflected round the southern tip of India have been invoked as the possible sources of these anomalies. Analogue ( Papamastorikas and Haerendel,1983) and numerical( Takeda and Maeda,1979; Ramaswamy et al.,1985) model studies seem to support this view. For confirmation of the existence of a channelling conductor between India and Sri Lanka,however,it is essential to have data from Sri Lankan stations. The limitation imposed by the non-availability of such data has been indicated earlier by Nitiyananda and Jayakumar(1981). Papamastorikas and Haerendel(1983),have pointed out the need for studies on the dependence of $\Delta Z/\Delta H$ ratios on period on either side of the Palk Strait to derive quantitative conclusions on the spatial extent of the conductivity enhancements. The only published data available from the Sri Lankan side so far have been those taken by Kannangara(1972) at Colombo,a coastal station,and by Kumaratnam(1981) at a number of inland stations,on the variation of $\Delta Z/\Delta H$ in the period range 20 - 600 sec. These data refer mainly to variations at day-time when the nonuniformity of the primary current source adds to the complexity of the problem and to stations which are less likely to be affected by currents channelled through the Palk Strait or deflected round the southern coast of Sri Lanka. In the present study,data on $\Delta Z/\Delta H$ and $\Delta D/\Delta H$ at Kondavil, $\Delta Z/\Delta H$ at Hikkaduwa and the ratio of the H components at Colombo and Hikkaduwa,all in the period range 20 - 600 sec,are presented and discussed. Kondavil is about 12.5 km from the nothern and western coasts of Jaffna Peninsula, Sri Lanka and Hikkaduwa is about 3 km from the south western coast of Sri Lanka. Colombo is about 0.5 km from the western coast of Sri Lanka.



The locations of the stations are shown in fig.1 in a map of India and Sri Lanka. Also shown in this map are Annamalainagar and Trivandrum, two permanent magnetic stations in India,and Adiramapattinam,a temporary station used by Thakur et al.,(1981) which is closest to Kondavil across the Palk Strait.

2.Data and analysis The data discussed in this paper refer to those recorded at Kondavil from 7 April 1973 to 27 April 1973, 29 June 1973 to 3 July 1973 and 16 July 1973 to 19 July 1973 and at Hikkaduwa from 9 February 1975 to 12 March 1975 using two air cored induction coils with galvanometer amplifiers.The details of the detectors and their operation have been described elsewhere( Kumaratnam,1981).The normal sensitivity of these detectors was about 0.01 nT $s^{-1}mm^{-1}$,but the sensitivities could be raised or lowered by adjusting the gain of the amplifiers. The availability of only two detectors limited the scope of the work considerably. At any station,only rates of change of two of the three components H,D and Z could be recorded simultaneously.At Kondavil continuous records of either dH/dt and dZ/dt or dH/dt and dD/dt were taken during the periods mentioned above.At Hikkaduwa,the recordings had to be terminated unexpectedly due to instrument failure and only simultaneous records of dH/dt and dZ/dt were taken during the relevant period.However,during this period,a trial run for three days was made of a newly constructed detector at the University of Colombo and recordings of dH/dt over a day and a night became available for comparison with those at Hikkaduwa. Records at all stations were taken at a chart speed of either 6 or 12 inch per hour.

Visual inspection of the records showed a strong correlation between D and H at Kondavil and also between Z and H at both Kondavil and Hikkaduwa.At Kondavil when H increased northwards,Z increased upwards and D westwards. At Hikkaduwa when H increased northwards,Z increased downwards.Accordingly, $\Delta Z/\Delta H$ and $\Delta D/\Delta H$ have been taken negative at Kondavil while at Hikkaduwa $\Delta Z/\Delta H$ is positive.These ratios were computed using the peak to peak amplitudes of signals which had clear sinusoidal or quasi-sinusoidal appearance and extended for more than one and a half full period. In fig.2, $\Delta Z/\Delta H$ values at Kondavil have been plotted as a function of period for day-time (6 – 18 hr) and night-time (18 – 6 hr). The day-time plots correspond to 305 signals and the night-time plot to 99 signals. The solid curve represents a smooth line drawn visually through the centroid of points and indicates the general trend of variation of $\Delta Z/\Delta H$ with period. In fig.3, a similar plot has been made for $\Delta D/\Delta H$ at Kondavil. 51 day-time events and 31 night-time events were used in this plot. A plot of $\Delta Z/\Delta H$ at Hikkaduwa as a function of period using 44 day-time events and 74 night-time events is shown in fig.4. In figs.5 and 7 simultaneous records of dH/dt taken during the night and day respectively on 16 February 1975 at Colombo and Hikkaduwa are shown. A power spectrum analysis of these records were made by the Blackman-Tukey method and the results are shown in figs.6 and 8 respectively.

3. Discussion of results

3.1 Anomalies at Kondavil It will be seen from fig.2 that the $\Delta Z/\Delta H$ ratios at Kondavil are small at short periods but increase in magnitude with increase in period rather rapidly at first from a value of about -0.1 at 30 sec period to about -0.35 at 120 sec period. The increase is gradual thereafter and the ratio reaches a value of about -0.55 in the period range 360 – 600 sec. No appreciable difference in the day-time and night-time values of the ratios could be seen. Similar variations in $\Delta D/\Delta H$ with period can be noticed from fig.3. In this case $\Delta D/\Delta H$ increases in magnitude from a value of about -0.1 at 30 sec period to about -0.3 at 120 sec period and remains more or less constant at this value for higher periods. The number of long period night-time signals available for computation of $\Delta D/\Delta H$ was small so that no firm conclusion could be made about the night-time values of $\Delta D/\Delta H$ in the long period range although the few long period signals available indicated the same value of -0.3 for the night-time ratio.



The higher period range in the present study, i.e about 360 – 600 sec, corresponds to the lower period range of the night-time SSC events studied by Nitiyananda et al.(1977) and Thakur et al.(1981) at Trivandrum, Annamalainagar and other Indian stations. The night-time $\Delta Z/\Delta H$ ratios at Trivandrum and Annamalainagar for this period range were reported to be 1.26 and 0.43 respectively and the corresponding $\Delta D/\Delta H$ ratios were 0.11 and -0.3 respectively (Takeda and Maeda, 1979). As the night-time inducing field in the equatorial regions does not have appreciable Z or D components, anomalous values of Z and D present in the geomagnetic variations in the equatorial regions have to be interpreted in terms of perturbations of the induced currents by the complex land ocean boundary and the presence of any anomalous conductors. As mentioned previously, the anomalies in the Z and D variations at Trivandrum and Annamalainagar cannot be interpreted in terms of coast effect alone. Further, the analogue model studies of Papamastorakis and Haerendel(1983) show that at periods corresponding to SSC and Bay events, there cannot be appreciable current channelling through the shallow waters of the Palk Strait. The night-time anomalies in the Z and D variations at Annamalainagar and other coastal stations in South Eastern India have been interpreted in terms of regionally induced currents channelled through a conducting region in the crust or upper mantle under the Palk Strait. Geology and tectonics of Southern India seem to indicate the presence of rift zones in the region which can provide such a conducting channel in the crust or upper mantle (Nitiyananda and Jayakumar, 1981; Thakur et al., 1981).

The present study reveals the existence of anomalies in Z and D variations at Kondavil which are comparable in magnitude to those observed at Annamalainagar. Further, the sense of variation of Z with respect to H, which is opposite to that at Annamalainagar and the sense of variation of D with respect to H, which is the same as that at Annamalainagar, reinforce the idea of current concentration in the Palk Strait which lies inbetween Annamalainagar and Kondavil. This view is further strengthened by the reported presence of large anomalies in the Z and D variations at Adiramapattinam(Thakur et al.,1981) in the same sense as that at Annamalainagar. Adiramapattinam is the closest Indian station to Kondavil across the Palk Strait.

For periods less than about 90 sec, the skin depth for an ocean of conductivity 3.6 S $m^{-1}$ would be less than 2 km which is the average depth of the ocean surrounding Sri Lanka. At these periods, appreciable currents will be induced mainly in the ocean waters surrounding Sri Lanka and India and channelled through the shallow waters of the Palk Strait and the underlying high conducting sediments which are reported to be about 3 km thick(Ramaswamy et al.,1985). At higher periods, substantial currents will be induced in the oceanic and continental crusts and the oceanic mantle as well and the currents will be channelled not only through the high conducting sediments but also through the proposed conducting channel in the crust or upper mantle under the Palk Strait. Detail model calculations of $\Delta Z/\Delta H$ as a function of period are not available for comparison with the present data. However, the calculations of Takeda and Maeda(1979) indicate that the concentration and diffusion into land of the perturbing currents due to channelling through the Palk Strait and deflection round the southern coast of Sri Lanka increase with increase in period. This might account for the increase in $\Delta Z/\Delta H$ values with period at Kondavil.

3.2 <u>Anomalies at Hikkaduwa</u> As mentioned previously, the $\Delta Z/\Delta H$ ratios at Hikkaduwa are positive and their values are much higher than those at Kondavil(fig.4). The ratios increase with increase in period from about 0.40 at 60 sec period to about 1.0 at 360 sec period at night-time. The corresponding values at day-time at these periods are about 0.50 and 1.4 respectively. Thus, there is a marked day-time enhancement of the $\Delta Z/\Delta H$ ratios at all periods. The night-time value of 1.0 for 360 sec period is comparable to the value of 1.26 observed at Trivandrum. Such high values are to be expected at Hikkaduwa and Trivandrum as these stations lie close to the concentration of induced currents deflected round the southern coast of Sri Lanka and the southern tip of India respectively.



Unlike Kondavil which lies close to the geomagnetic equator, Hikkaduwa is situated below the edge of the equatorial electrojet. At day-time, a Z component in the primary field variation could be expected at Hikkaduwa. This Z variation will be in the same sense as that due to the induced currents deflected round the southern coast of Sri Lanka and the two variations will reinforce each other producing the observed enhancement of the $\Delta Z/\Delta H$ ratios at day-time. Additional effects due to the difference in the day-time and night-time induced current pattern may also be present.

At Hikkaduwa anomalies were noted in the H variations as well. A string of three Pi2 events were recorded at Hikkaduwa and Colombo on the night of 16 February 1975(fig.5). The sensitivity of the detector at Colombo was 1.18 ± 0.02 times the sensitivity of the detector at Hikkaduwa at all periods. It will be apparent from fig.5 that even after allowing for the difference in sensitivities, the dH/dt values at Hikkaduwa are lower than those at Colombo for periods corresponding to those of the events recorded. The records were digitised every 10 sec and the power spectra of the signals computed by the Blackman-Tukey method using a total of 320 points and a lag of 64. It is seen(fig.6) that the power is concentrated within the period range 24-72 sec. The ratio of the power at Hikkaduwa to that at Colombo in the different frequency bands within this range is more or less constant and is about 0.46 giving a value of 0.68 for $\Delta H_H/\Delta H_C$, the ratio of amplitudes of H variations at Hikkaduwa and Colombo. When the signals were considered as three separate events and their power spectra computed separately no substantial difference in the result was obtained. A similar suppression of H values at short periods was also reported by Singh et al.(1982) at Trivandrum. The reduction in the values of H at Hikkaduwa at short periods in relation to those at Colombo can be understood qualitatively in terms of the model calculations given by Takeda and Maeda (1979) and their figs.2 and 3 giving the contours of the additional (perturbing) currents when the primary inducing field is northwards. Hikkaduwa is close to the eastward flowing perturbing currents, the effect of which will be to reduce the northward horizontal component at Hikkaduwa. At low periods the effect of these perturbing currents at Colombo will be small and the net result will be an enhancement of the H component at Colombo in relation to that at Hikkaduwa. At higher periods, however, the perturbing currents will diffuse far inland and the H variations at Colombo too will be suppressed. Similar arguements will apply to the suppression of H variations at Trivandrum reported by Singh et al. (1982).

At day-time an increased enhancement of H variations at Colombo in relation to that at Hikkaduwa, presumably due to the effect of the equatorial electrojet, was noticed for short period variations. A visual inspection of simultaneous records of dH/dt taken at Colombo and Hikkaduwa at day-time on the same day, that is 16 February 1975, reveals that short period variations in the Colombo record are supressed in the Hikkaduwa record (fig.7). This is borne out more clearly from the power spectra of the signals (fig.8). In this case a total of 240 points digitised at 10 sec interval and a lag of 40 were used in the computation of the power spectra. The power is concentrated in bands of periods within the ranges 27–36 sec, 36–45 sec, 45–96 sec and 96–575 sec and in these ranges the ratio of power at Hikkaduwa to that at Colombo are about 0.13, 0.32, 0.82 and 0.86 respectively, corresponding to ratios of $\Delta H_H/\Delta H_C$ of 0.36, 0.57, 0.90 and 0.93 respectively. Thus, at the short period end the $\Delta H_H/\Delta H_C$ ratios are lower than the corresponding night-time values. It should however be borne in mind that these conclusions are based on the analysis of records taken only on one day and one night.

4. __Conclusions__ Anomalies in geomagnetic variations in the period range 20 – 600 sec have been observed at Kondavil and Hikkaduwa, two stations in the equatorial electrojet belt close to the northern and south western coasts respectively of Sri Lanka. The anomalies at Kondavil can be explained qualitatively in terms of induced currents channelled through conducting regions under the Palk Strait and those at Hikkaduwa in terms of induced currents deflected round the southern coast of Sri Lanka. A day-time enhancement of $\Delta Z/\Delta H$ ratios at Hikkaduwa at all periods and a similar enhancement of $\Delta H_C/\Delta H_H$, the ratio of H components at Colombo and Hikkaduwa at short periods were observed. Detail model calculations



of $\Delta Z/\Delta H$ as a function of period and magnetic array studies in the northwestern and western coasts of Sri Lanka are necessary for a quantitative interpretation of the data and the delineation of the proposed conducting channel under the Palk Strait.

__Acknowledgements__ The experimental part of the work reported in this paper was done while the author was a member of the staff of the Department of Physics, University of Colombo, Sri Lanka. The analysis of the data was made during a visit to the International Centre for Theoretical Physics (ICTP), Italy, as an Associate. The author wishes to thank the University of Colombo for the facilities provided and the ICTP for the Associateship. He would like to thank Professor Abdus Salam, the International Atomic Energy Agency and UNESCO for hospitality at the International Centre for Theoretical Physics, Trieste.

References

Kannangara, M.L.T., 1972. Some polarization characteristics of Pc3-5 micropulsations observed in Colombo, Ceylon. J.Geophys.Res., 77:6161-6167.

Kumaratnam, K., 1981. Spatial dependence of day-time vertical polarisation of Pc3-5 micropulsations in Sri Lanka. J.Atmos.Terr.Phys., 43:1289-1294

Nityananda, N., Agarwal, A.K. and Singh, B.P., 1977. Induction at short periods in the horizontal field variations in the Indian peninsula. Phys.Earth.Planet. Inter., 15:5-9

Nityananda, N. and Jayakumar, D., 1981. Proposed relation between anomalous geomagnetic variations and the tectonic history of South India. Phys.Earth Planet.Inter., 27:223-228

Papamastorakis, I. and Haerendel, G., 1983. An analogue model of the geomagnetic induction in the South Indian ocean. J.Geophys., 52:61-68

Rajaram, M., Singh, B.P., Nityananda, N. and Agarwal, A.K., 1979. Effect of the presence of a conducting channel between India and Sri Lanka island on the features of the equatorial electrojet. Geophys.J.R.Astron.Soc., 56:127-138

Ramaswamy, V., Agarwal, A.K. and Singh, B.P., 1985. A three-dimensional numerical model study of electromagnetic induction around the Indian peninsula and Sri Lanka island. Phys.Earth Planet.Inter., 39:52-61

Singh, B.P., Agarwal, A.K. and Carlo, L., 1982. Anomalies in H at Indian equatorial stations and their effect on equatorial enhancements. J.Atmos. Terr.Phys., 44:241-244

Srivastava, B.J. and Abbas, H., 1980. An interpretation of the induction arrows at Indian stations. J.Geomag.Geoelectr., 32:Suppl.I., SI187-SI196

Takeda, M. and Maeda, H., 1979. Effect of the coastline configuration of South India and Sri Lanka regions on the induced field at short period. J.Geophys., 45:209-218

Thakur, N.K., Mahashabde, M.V., Arora, B.R. and Singh, B.P., 1981. Anomalies in geomagnetic variations on Peninsular India near Palk Strait. Geophys.Res. Lett., 3:947-950



Caption to figures

Fig.1 Map of India and Sri Lanka showing location of stations.

Fig.2 Day-time and night-time plots of $\Delta Z/\Delta H$ at Kondavil as a function of period.

Fig.3 Day-time and night-time plots of $\Delta D/\Delta H$ at Kondavil as a function of period.

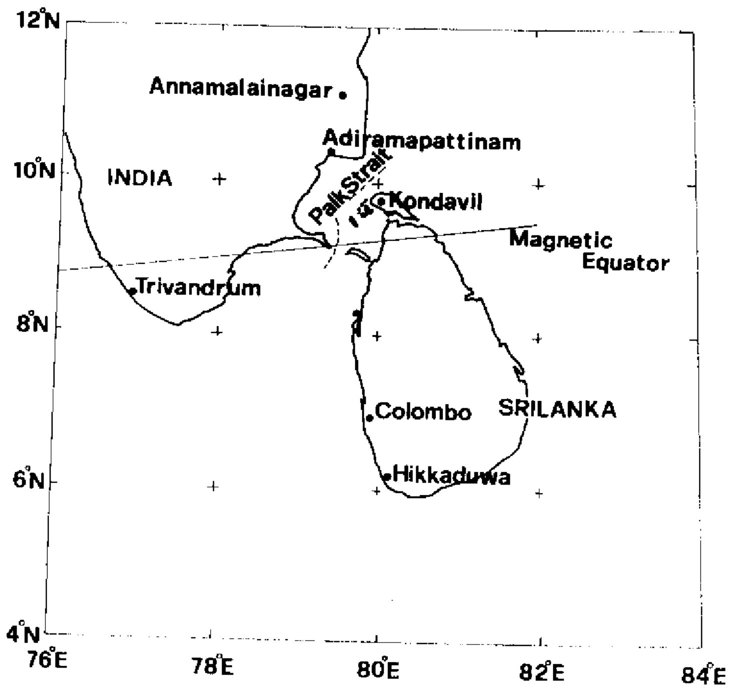
Fig.4 Day-time and night-time plots of $\Delta Z/\Delta H$ at Hikkaduwa as a function of period.

Fig.5 Traces of simultaneous records of $dH/dt$ taken at midnight on 16 February 1975 at Colombo and Hikkaduwa (the sensitivity of the detector at Colombo was greater by a factor of $1.18 \pm 0.02$).

Fig.6 Power spectra of records shown in fig.5.

Fig.7 Traces of simultaneous records of $dH/dt$ taken at noon on 16 February, 1975 at Colombo and Hikkaduwa (The sensitivity of the detector at Colombo was greater by a factor of $1.18 \pm 0.02$).

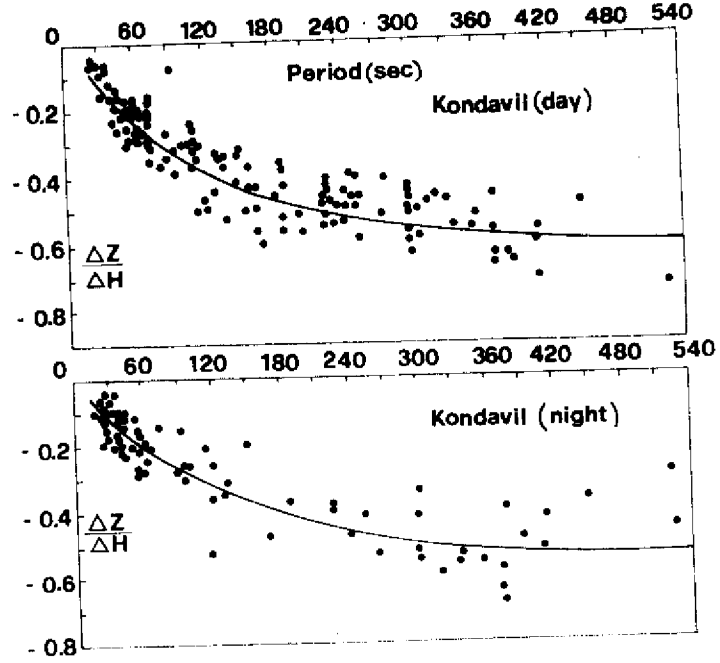
Fig.8 Power spectra of records shown in fig.7.



12°N
10°N
8°N
6°N
4°N
76°E
78°E
80°E
82°E
84°E
Annamalainagar
Adiramapattinam
INDIA
Palk Strait
Kondavil
Magnetic
Equator
Trivandrum
Colombo
SRILANKA
Hikkaduwa


Fig.1





0 60 120 180 240 300 360 420 480 540
Period (sec)
Kondavil (day)
-0.2
-0.4
-0.6
-0.8
ΔZ/ΔH
0 60 120 180 240 300 360 420 480 540
Kondavil (night)
-0.2
-0.4
-0.6
-0.8
ΔZ/ΔH


Fig.2

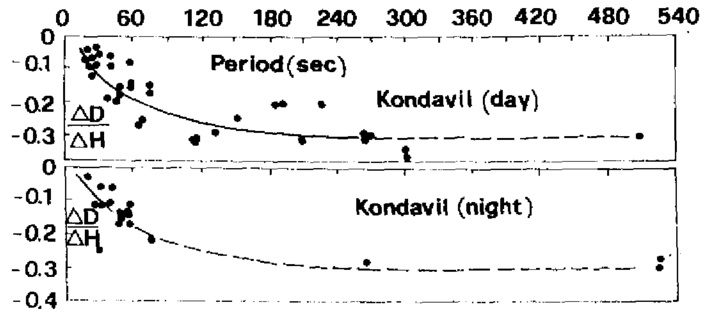

0 60 120 180 240 300 360 420 480 540
Period(sec)
Kondavil (day)
ΔD/ΔH
0 -0.1 -0.2 -0.3
Kondavil (night)
-0.4

Fig.3



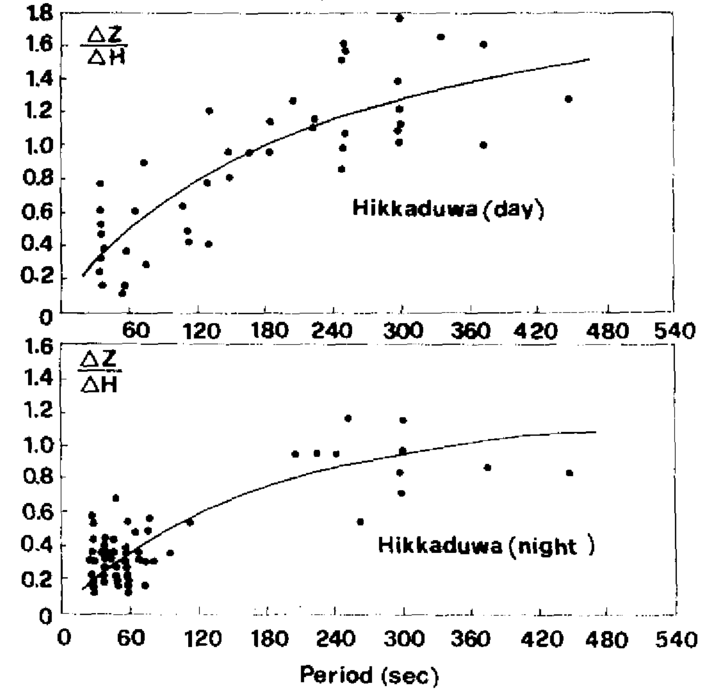

ΔZ/ΔH
1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0
Hikkaduwa (day)
Hikkaduwa (night )
0 60 120 180 240 300 360 420 480 540
Period (sec)

Fig.4

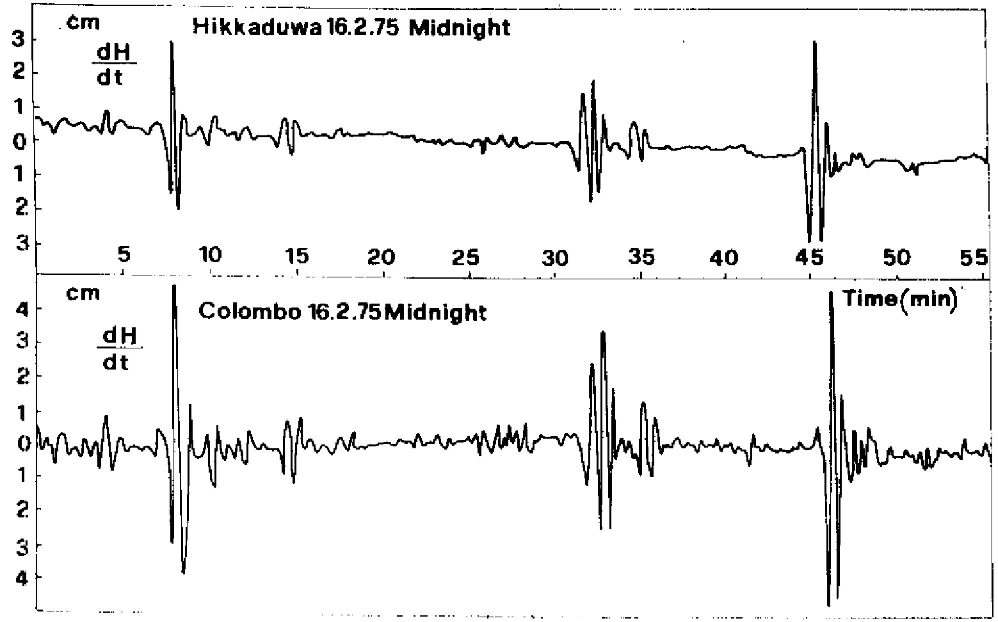

cm
dH/dt
Hikkaduwa 16.2.75 Midnight
3
2
1
0
1
2
3
5
10
15
20
25
30
35
40
45
50
55
cm
dH/dt
Colombo 16.2.75 Midnight
Time(min)
4
3
2
1
0
1
2
3
4

Fig.5

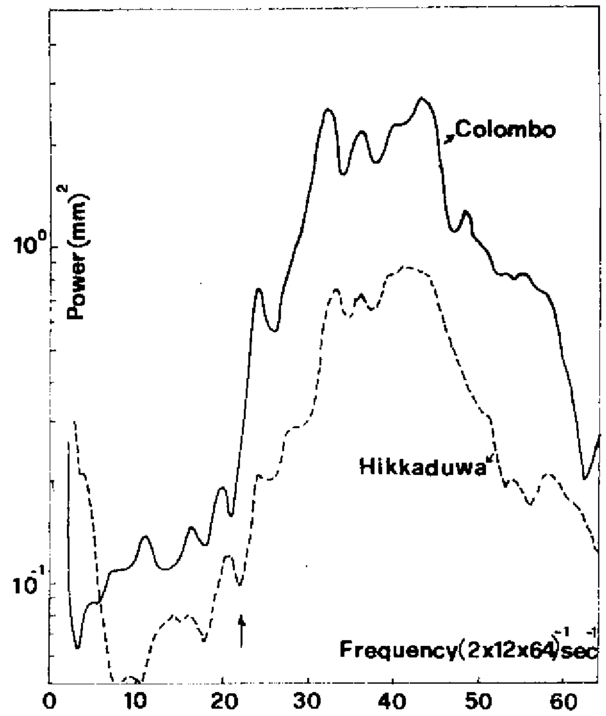
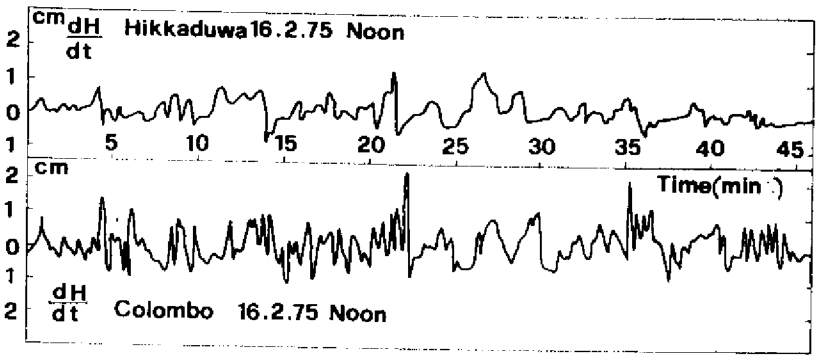

Colombo
Power $(mm)^2$
$10^0$
$10^{-1}$
Hikkaduwa
Frequency$(2x12x64)^{-1}sec^{-1}$
0
10
20
30
40
50
60

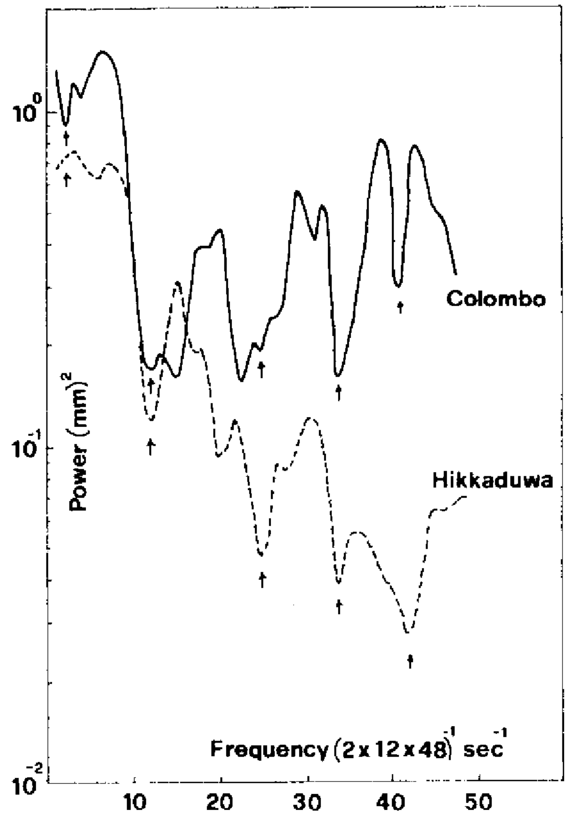
Fig.6



cm dH/dt Hikkaduwa 16.2.75 Noon
2
1
0
1
5
10
15
20
25
30
35
40
45
2 cm
Time(min.)
1
0
1
dH/dt Colombo 16.2.75 Noon
2


Fig.7





$10^0$
$10^{-1}$
$10^{-2}$
Power $(mm)^2$
Colombo
Hikkaduwa
Frequency $(2\times12\times48)^{-1}$ $sec^{-1}$
10
20
30
40
50


Fig.8