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LOG Id: LOG_0032
LOG Titel: Effect of the coastline configuration of south Indian and Sri Lanka regions on the induced field at short period
LOG Typ: article

Übergeordnetes Werk

Werk Id: PPN1015067948
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J. Geophys. 45, 209–218, 1979

Journal of Geophysics

Effect of the Coastline Configuration of South Indian and Sri Lanka Regions on the Induced Field at Short Period

M. Takeda and H. Maeda*

Geophysical Institute, Kyoto University, Kyoto 606, Japan

Abstract. Deformation of induced currents by the Palk Strait and the coasts of India and Sri Lanka (Ceylon) is studied by data analysis and model calculation in the cases of SSC's and bay disturbances at night. In the model calculation a thin flat layer model in which only contrast of conductivity due to the distribution of land and depth of sea is taken into account is used, the inducing field is assumed to be parallel to the geomagnetic axis, and the effect of self induction is included. It is found that the anomalous distribution of geomagnetic SSC's or bays in the South Indian region during the nighttime could be explained, at least qualitatively, by abnormal current patterns caused by the Palk Strait and the coasts of India and Sri Lanka. It is also found that a large phase lag is expected in the induced field especially in the *D* and *Z* components at shorter periods, as an effect of self induction.

Key words: Geomagnetism – Induction – Palk strait.

1. Introduction

It was often pointed out that geomagnetic variations observed on the ground are much affected by oceans. In a previous research note (Takeda and Maeda, 1978) we have suggested the possibility that anomalously large amplitudes in the horizontal component of SSC's at Annamalainagar in India may be resulted from a concentration of induced currents at the Palk Strait. Also, Nityananda et al. (1977) has recently examined mean direction of "anomalous" horizontal variations of SSC's and bays at Annamalainagar and Trivandrum, and mentioned that the reason of this anomalies may be caused by the induced currents along the coastline and through the Palk strait. In this paper, we first show that not only SSC's but also bays have abnormally large horizontal amplitude at Annamalainagar in the nighttime, and then by model calculations by taking a

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* Also at the Data Analysis Center for Geomagnetism and Spacemagnetism, Faculty of Science, Kyoto University

0340-062X/79/0045/0209/$02.00

self-induction term into account, we attempt to explain this anomaly in terms of induced currents in the sea around the Indian Peninsula and through the Palk Strait.

2. Data Analysis

In a previous note (Takeda and Maeda, 1978) we studied the amplitude distribution of *H* component of nighttime SSC's in the equatorial zone of American, Pacific and Indian regions, suggesting different effects of induced currents in the Earth. In the Pacific region the distribution is rather uniform because of uniform induced currents. However, in the Indian region a quite different distribution is seen, and we suggested that the anomaly of this kind may be caused by induced currents in the Palk Strait.

In order to examine the anomaly in the Indian region, we have analysed the *H* component of bays during the IGY, 1957–1958, in the nighttime, but an apparent anti-equatorial enhancement is also seen in bays as well as SSC's. Furthermore, as is shown by Nityananda et al. (1977) and Singh et al. (1977), the amplitude of *Z* component observed at Annamalainagar and Trivandrum at night is so large (equal or more than the *H* component) that it cannot be explained without considering a current-density gradient in the Earth.

3. Method of Calculation

The method of calculation in this study is based on the theory of electromagnetic induction within a non-uniform thin plane sheet conductor. It was established by Price (1949) and applied to actual problems by Sasai (1968) and Honkura (1972).

Assuming that the inducing field is parallel to the geomagnetic axis, we can put the potential of this field as

$$We = A_0 \exp(i\omega t + \lambda z) \sin(\lambda x) \tag{1}$$

where ω is equal to the angular frequency of the inducing field, z the upward distance measured from the Earth's surface, x the northward distance measured from the geomagnetic equator, A_0 is a constant and we assumed it to be unity, and $1/\lambda$ is defined as the wavelength. Considering that the space of the inducing field is about as large as that of the Earth, $1/\lambda$ could be put to the Earth's radius, though the value of λ does not much effect on the results. Then we can write the induced current function Ψ_0 in a conductor (sea) having uniform depth as

$$\Psi_0 = 2(1-\alpha i)/(1+\alpha^2) \exp(i\omega t) \sin(\lambda x) \tag{2}$$

where $\alpha = 2\lambda\rho_0/(\omega\mu)$, $\rho_0 = 1/(\sigma_0 D_S)$, σ_0 is the conductivity of the sea water which is supposed to be 4 S/m ($=4$ mho/m), D_S is the assumed uniform sea depth, and μ is the permeability ($4\pi\times10^{-7}$ H/m). And the total current function Ψ may be written as

$$\Psi = \Psi_0 + \psi \tag{3}$$

where ψ is regarded as a current function due to anomalous (or additional) current distribution.

The equation to be solved thus becomes

$$\rho \Delta \psi + \nabla \rho \cdot \nabla \psi = -(\rho - \rho_0) \Delta \Psi_0 - \nabla(\rho - \rho_0) \cdot \nabla \Psi_0 + \mu \frac{\partial z^*}{\partial t} \tag{4}$$

where ρ is inverse of the integrated conductivity. If we define the equivalent sea depth D, it can be written as $1/(\sigma_0 D)$. Z^* is the vertically downward component of the magnetic field generated by the current function ψ, and written by Biot-Savart's law as

$$Z^*(0, 0) = \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\infty} \frac{1}{r} \frac{\partial \psi}{\partial r}\, dr\, d\theta = -\frac{1}{4\pi} \int_0^{2\pi} \int_0^{\infty} \frac{\psi(r, \theta) - \psi(0, 0)}{r^2}\, dr\, d\theta \tag{5}$$

where (r, θ) is the polar coordinate originated at a point the value at which we require. Substituting (2) and (5) into (4), we obtain an equation which contains ψ only. Thus, solving this equation by the relaxation method, we can get the value of ψ as a function of place. Once we get ψ and so Ψ, using the relation between magnetic potential by the inducing currents W and current function Ψ

$$W = \Psi/2 \tag{6}$$

the magnetic fields (H, northward; D, eastward; Z, downward component) by the induced current are obtained as follows:

$$\begin{aligned}
H &= -\frac{\partial W}{\partial \kappa} = -\frac{1}{2} \frac{\partial \Psi}{\partial \kappa} \\
D &= -\frac{\partial W}{\partial y} = -\frac{1}{2} \frac{\partial \Psi}{\partial y} \\
Z &= -\frac{1}{4\pi} \int_0^{2\pi} \int_0^{\infty} \frac{\Psi(r, \theta) - \Psi(0, 0)}{r^2}\, dr\, d\theta = -\frac{1}{4\pi} \int_0^{2\pi} \int_0^{\infty} \frac{\psi(r, \theta) - \psi(0, 0)}{r^2}\, dr\, d\theta
\end{aligned} \tag{7}$$

where (r, θ) is the same coordinate as in Eq. (5).

In the actual calculation, D_S is taken to be 2000 m, the mesh interval to be 15 Km, and a 1200 Km square mesh putting the Palk Strait near the center of the square is adopted. The isobaths in the Indian ocean are shown in Fig. 1, together with three magnetic observatories (Annamalainagar, Kodaikanal, and Trivandrum). Using this map, the equivalent sea depths are determined as follows: In the sea region deeper than 2000 m, D is taken to be 2000 m, in the region of depth between 1000 m and 2000 m, D to be 1500 m, and in the region between 200 m and 1000 m, D to be 600 m. In the land region $D(=D_0)$ is assumed to be 10 m at first and 100 m in the next. When D_0 is taken to be 10 m, D in the region of depth between 0 m and 200 m is taken to be 100 m, and when $D_0 = 100$ m it is taken to be 200 m. As for the boundary condition, ψ is put to be 0 at the sides of the largest mesh square, and this is equivalent to the assumption

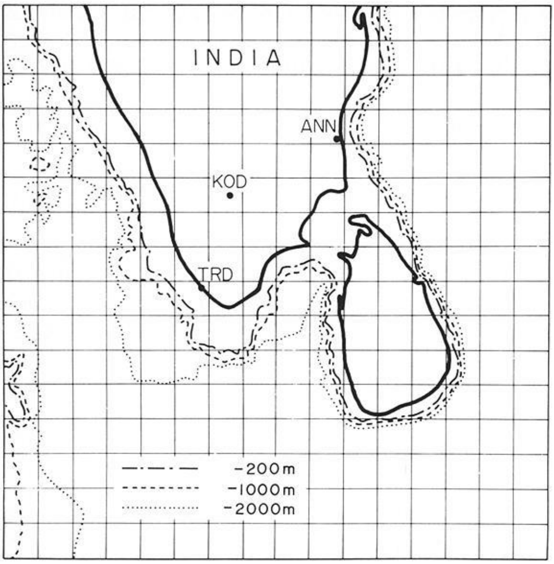

Fig. 1. Distribution of the Indian magnetic observatories (Annamalainagar, Kodaikanal, and Trivandrum) and the isobaths (−200 m, −1000 m, and −2000 m) in the Indian ocean

that the indiced (westward) current is not disturbed outside of this mesh, and current density is constant on the west or east side.

In the calculation of the self induction term [Eq. (5)], we summed the terms up to the points at a distance of five times (75 Km) of mesh intervals. Assuming that the additional current function decreases and tends to zero as inversely propotional to the distances, we express the remaining terms by integral. So the form of self induction term used in the actual calculation is as follows:

$$Z^*(i,j) = -\sum_{\substack{k,\,l=-5\\ k^2+l^2\neq 0}}^{5} \frac{\psi(i+k,j+l)-\psi(i,j)}{4\pi(k^2+l^2)^{3/2}\,d} - \frac{1}{4\pi}\int_{0}^{2\pi}\int_{d_r}^{\infty} \frac{\psi_m \times \frac{d}{r} - \psi(i,j)}{r^2}\,dr$$

$$= -\sum_{\substack{k,\,l=-5\\ k^2+l^2\neq 0}}^{5} \frac{\psi(i+k,j+l)-\psi(i,j)}{4\pi(k^2+l^2)^{3/2}\,d} - \frac{\psi_m}{4d_r} + \frac{\psi(i,j)}{2d_r} \qquad (8)$$

where d is the mesh interval (15 Km), d_r is the radius of a circle (105 Km) which has the same area as the eleven mesh interval square, and ψ_m is the mean of ψ on the sides of it. Other methods, such as using only first term of Eq. (8) or summing from $k, l = -10$ up to 10, were studied, but they did not give so much different results. However, in the calculation of the induction of 1 min period, the self induction term cannot be neglected. If we do not take this term into account, the effect of the inhomogeneity of conductivity is overestimated, but in the imaginary part (phase shift) it is underestimated. Calculations were made for two inducing geomagnetic fields, one has a 1 min period that may correspond to SSC's, and the other has a 60 min period to bays.

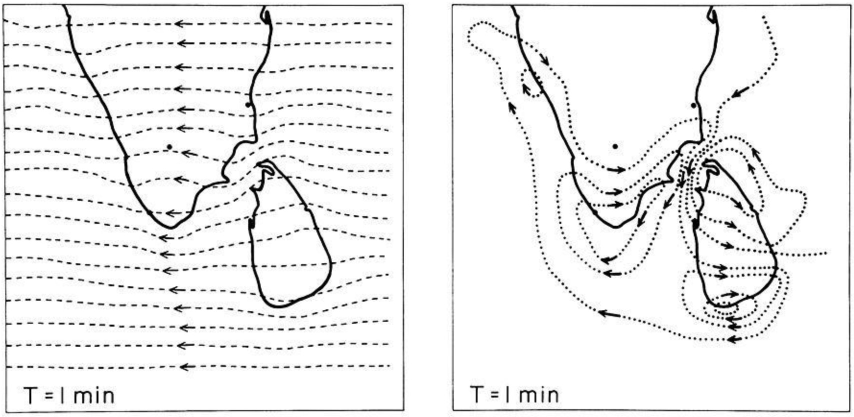

Fig. 2. Streamlines of the total induced currents for the inducing field of 1 min period (*left*) and those of the additional part (*right*). When the inducing field changes by 1 nT, the current flowing between the adjacent lines is 100 A in the left and 25 A in the right

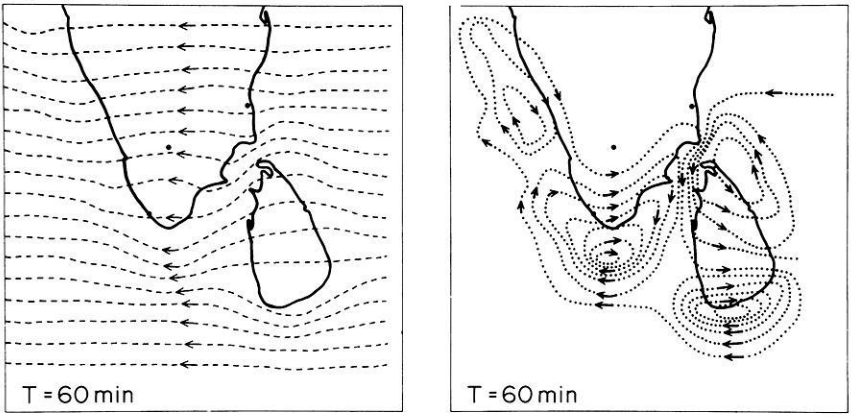

Fig. 3. Streamlines of the total induced currents for the inducing field of 60 min period (*left*) and those of the additional part (*right*). When the inducing field changes by 1 nT the current flowing between the adjacent lines is 100 A in the left and 25 A in the right

4. Results and Discussion

The total current patterns in the case of $D_0 = 10$ m are shown on the left-hand side of Fig. 2 (for 1 min) and Fig. 3 (for 60 min). It is generally seen that the streamlines are influenced by the distribution of Indian Peninsula and Sri Lanka. In order to see more clearly the deformation of induced currents, the additional current parts are shown on the right-hand side of Figs. 2 and 3. It is clearly seen that the induced currents are much distorted along the coasts of India and Sri Lanka, especially in regions of the south of India and Sri Lanka and in the Palk Strait. These kinds of deformation are usually called "peninsula effect" and "strait effect", respectively.

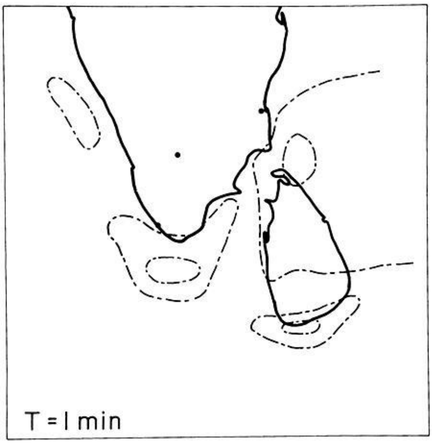

Fig. 4. Streamlines of the imaginary part of induced current function for the inducing field of 1 min period. When the inducing field changes by 1 nT, the current flowing between the adjacent lines is 25 A

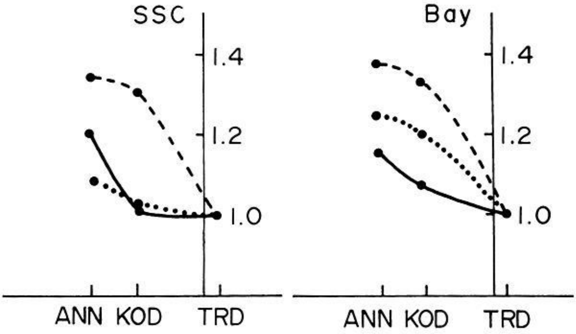

Fig. 5. Distribution of the observed (*full lines*) and calculated (*broken lines* for $D_0 = 10$ m and *dotted lines* for $D_0 = 100$ m) amplitudes of SSC's (*left*) and bays (*right*)

Figure 4 shows the distribution of the imaginary part of the current function for 1 min period, and this result means that the induced current shows a phase shift from the inducing field because of self induction. This phase shift can be regarded as the total phase shift, because in the uniform state the imaginary part is very small (α times the real part, where α is 3×10^{-4} for 1 min period and 0.018 for 60 min period). Such a phase shift by the additional current was very small for the 60 min period and so we did not show here.

Since the result of these distorted currents can be observed as geomagnetic variations, we have calculated the magnetic effect of the inducing and induced currents. Figure 5 shows the distribution of observed (full line) and calculated (broken or dotted lines) amplitudes of H-component for SSC's (left) and bays (right) at Annamalainagar, Kodaikanal, and Trivandrum normalized at Trivandrum. In this figure the broken lines are for the case of $D_0 = 10$ m, and the dotted line for the case of $D_0 = 100$ m. The ratio calculated for $D_0 = 10$ m is larger than the observed one at both Kodaikanal and Annamalainagar, and that for $D_0 = 100$ m is nearly equal at Kodaikanal and smaller at Annanalainagar for SSC's. But they are both larger for bays.

One of the most difficult problems in calculation of this kind would be the estimation of the conductivity of land. If we suppose that the land conductivity is 5×10^{-3} times the sea conductivity, the assumption of $D_0 = 10$ m means that the current induced in the sea does not sink so deep and flows horizontally in the land, whereas that of $D_0 = 100$ m means that it spreads in the land about ten times deeper than in the sea. As is seen in Fig. 5 the observed ratio is almost between the results for these two D_0 values, so that for SSC's the spreading of induced currents in the land would be between one and ten times the assumed sea depth if other assumption are justified.

The distribution of calculated magnetic effects is shown in Fig. 6a–c for the components of H, D, and Z respectively, in the case of $D = 10$ m. The real part is shown on the left-hand side, and the imaginary part on the right-hand side. The dot-dash lines represent the contour of undisturbed values for real H component, and of zero values for the others. As will be expected from the distribution of induced currents, the magnetic effects are much deformed along the coasts of India and Sri Lanka and around the Palk Strait, resulting in abnormal geomagnetic variations at Trivandrum and Annamalainagar. As for the Z component, the calculated and observed Z/H ratios for SSC's are shown in Table 1. From this table it can be seen that at Annamalainagar the assumption of $D_0 = 10$ m is good, but at Trivandrum and Kodaikanal the result of $D_0 = 100$ m is better. It might result from the scale of current concentration. That is, at Annamalainagar the currents which contribute to Z flow mainly in the Palk Strait, but at Trivandrum and Kodaikanal they flow beyond the tip of the Indian Peninsula, and scale of the former is smaller than that of the latter. If we consider that some distance is necessary for the induced currents to spread and sink into the land, this is natural. Of course especially at Trivandrum the agreement between the observed and calculated values is not so good even in the case of $D_0 = 100$ m. This might be due to the step-like conductivity configuration that we used in the present calculation, or due to the boundary condition we used. For example, a conductivity configuration of larger scale such as inferred by Rikitake (1967) might have to be considered for the determination of boundary condition. For the D component, the calculated and observed D/H ratios for SSC's are shown in Table 2. Observed D/H ratios are generally smaller than the calculated ones. This may be attributed to the inducing field. For example, if the inducing field is not parallel to the geomagnetic axis but tilted by about six degrees, it has D component one tenth as large as H component, and so the calculated result for $D_0 = 10$ m agrees better with the observed one. In fact, Nityananda et al. (1977) show that D/H ratio of SSC's in the nighttime is negative at Alibag and Hyderabad, too.

Furthermore, as a result of self induction term, the imaginary part is not small and so it cannot be neglected, especially for the inducing field of short period. For the H component the imaginary part is relatively small, but for the D and Z components it is rather large, because the "normal" field has large H component but no D component and small Z component. Therefore, a large phase lag is expected in the D and Z components. This tendendy is emphasized when the resistivity gradient is comparatively small, because in this case the third term on the right-hand side of Eq. (4) is more effective compared with the

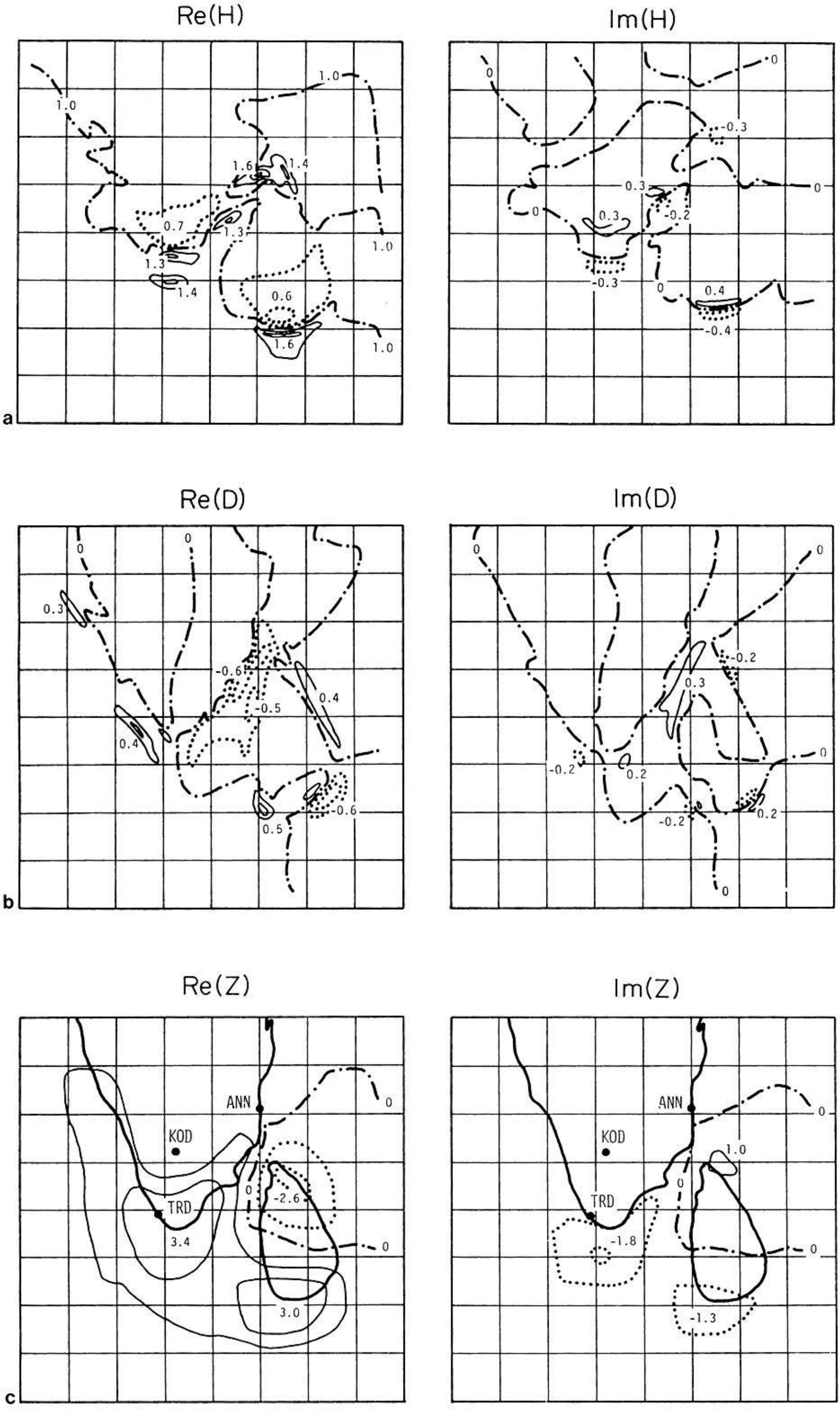
Re(H)
1.0
1.0
1.6
1.4
0.7
1.3
1.3
1.4
0.6
1.6
1.0
1.0
Im(H)
0
0
-0.3
0.3
0
0
-0.2
0.3
-0.3
0
0.4
-0.4
a
Re(D)
0
0
0.3
-0.6
-0.5
0.4
0.4
0.5
-0.6
Im(D)
0
0
-0.2
0.3
-0.2
0.2
0
-0.2
0.2
0
b
Re(Z)
ANN
0
KOD
0
-2.6
TRD
3.4
0
3.0
Im(Z)
ANN
0
KOD
1.0
0
TRD
-1.8
0
-1.3
c

Table 1. Observed and calculated values of Z/H in the case of $T=1$ min. Observed values of Z/H are obtained by Singh et al. (1977)

Stations	Annamalainagar	Kodaikanal	Trivandrum
Observed values (SSC's at night)	0.43	0.44	1.26
Calculated values ($T=1$ min)			
$D_0=10$ m	0.43	0.57	4.73
$D_0=100$ m	0.05	0.48	1.72

Table 2. Observed and calculated values of D/H in the case of $T=1$ min. Observed values of D/H are obtained by Nityananda et al. (1977)

Stations	Annamalainagar	Kodaikanal	Trivandrum
Observed values (SSC's at night)	−0.30	−0.18	0.11
Calculated values ($T=1$ min)			
$D_0=10$ m	−0.21	−0.04	0.25
$D_0=100$ m	−0.07	−0.02	0.11

first and second terms. So, the phase lag is larger in the case of $D_0=100$ m than $D_0=10$ m. If these phase lags really exist, they could be observed in geomagnetic pulsations more easily than in SSC's or bays, and so the observation of this kind might help to reveal the spreading rate of the induced current. Anyway, more dense network observations in this region (along India-Sri Lanka line including the Palk Strait) would be important to make clear the conductivity configuration there.

Acknowledgements. We ackowledge Miss T. Obata for assistance in preparing the manuscripts. The data used in this study were obtained from the World Data Center C2 for Geomagnetism, and the numerical analyses were made by using facilities at the Data Analysis Center for Geomagnetism and Spacemagnetism and also at the Data Processing Center of Kyoto University.

References

Honkura, Y.: Geomagnetic variation anomaly on Miyake-jima Island. J. Geomag. Geoelect. **23**, 307–333, 1972

Nityananda, N., Agarwal, A.K., Singh, B.P.: Induction at short periods in the horizontal field variations in the Indian Peninsula. Phys. Earth Planet. Inter. **15**, P5–P9, 1977

Fig. 6a–c. Distribution of the ratios of the induced magnetic field [H (*a*), D (*b*) and Z (*c*) components] to the inducing field of 1 min period for the real (*left*) and imaginary (*right*) parts, where the imaginary parts indicate the phase lag of the induced field from the inducing field. *Dot-dash lines* represent the standard values (i.e., 1 for real H component and 0 for the other components), *thin solid lines* the larger values and *dotted lines* the smaller values. *Thick solid lines* in (*c*) represent the coastline. Values in this figure except for the standard values represent the maximum or minimum values

Price, A.T.: The induction of electric current in non-uniform thin sheets and shells. Quart. J. Mech. Appl. Math. **2**, 283–310, 1949

Rikitake, T.: Electromagnetic induction within non-uniform plane and spherical sheets. Bull. Earthq. Res. Inst. **45**, 1229–1294, 1967

Sasai, Y.: Spacial dependence of short period geomagnetic fluctuations on Oshima Island (2). Bull. Earthq. Res. Inst. **46**, 907–926, 1968

Singh, B.P., Nityananda, N., Agarwal, A.K.: Induced magnetic variations in the Indian Peninsula, Acta Geodaet. Geophys. Montanist. Acad. Sci. Hung. **12**, 65–72, 1977

Takeda, M., Maeda, H.: Note on geomagnetic variations in the equatorial zone. J. Geomag. Geoelect. **30**, 121–123, 1978

Received May 2, 1978; Accepted February 3, 1979