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A Possibility to Distinguish Between Ionospheric and Magnetospheric Origin of Low Latitude Magnetic Perturbations

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Abstract. The ratio of ΔZ and ΔH for short period magnetic variations as observed at the Southern Indian station Annamalainagar can be used to distinguish contributions from primary currents flowing in the ionosphere from those flowing in the magnetosphere. The signature of an ionospheric source is $\Delta Z = 0$. Correlation coefficients for ΔZ and ΔH are given for Annamalainagar and Trivandrum for pure perturbations of either kind. They can be used to separate the source fields in mixed ionospheric/magnetospheric events. The quality of such a separation is demonstrated and examples of simple applications both to individual events and statistical material are given.

Key words: Annamalainagar – Trivandrum – Coast effect – Sources of magnetic variations

Introduction

The separation of geomagnetic perturbations observed on the ground into external and internal contributions has been a subject of great interest since the pioneering work of Gauss (1839) and Schuster (1889). They recognized that the magnetic variations were due to externally flowing currents with contributions from earth currents induced by the former. The non-uniform distribution of electrical conductivity in the outer layers of the crust, i.e. in and under the oceans and under the continents, creates quite complex paths of the induced earth currents and leads to characteristic responses of the horizontal and vertical components of the variation field. Far inland, the vertikal component is normally small, except near conductivity anomalies or close to concentrations of the primary currents, like the auroral or equatorial electrojets. However, as one approaches a coast, one finds an increasing value of the vertical (Z-) component. The variation vector tends to lie in a plane that is inclined with respect to the horizontal. Wiese (1962) and Parkinson (1964) studied the orientation of this plane, whose normal vector points towards the better conductor and thus indicates where the induced earth currents tend to be concentrated. Much work on this effect has been done subsequently by various authors. A recent review has been given by Parkinson and Jones (1979).

Beyond separating the external and internal contributions to the magnetic variations observed on the ground, it is desirable to further distinguish for the external sources between currents located in the *ionosphere* and in the higher *magnetosphere*. This is obviously possible with the aid of low orbiting satellites. In particular, the identification of field-aligned currents has been achieved by Zmuda et al. (1970) and Iijima and Potemra (1976) with data from polar orbiting satellites. A rich literature emerged from this technique.

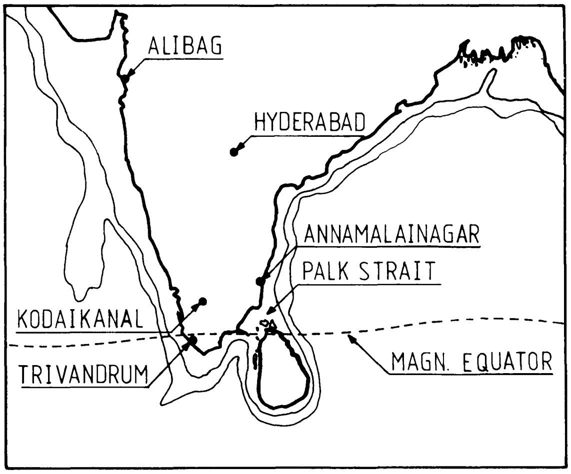


Fig. 1. Location of magnetic observatories in Southern India

In spite of the availability and great significance of such satellite data, there remains much interest in possibilities of separating magnetospheric from ionospheric contributions to the primary fields from the study of ground-based measurements alone. For high latitudes this has been undertaken by Hughes and Rostoker (1979) and Baumjohann et al. (1980) by using essentially the latitudinal profile of the D-component across the auroral oval.

Even with data from only one ground station a separation of the ionospheric and magnetospheric contributions may be successfully achieved. This possibility arises near the geomagnetic equator where the ionospheric current is heavily concentrated in the so-called Equatorial Electrojet (EEJ), in contrast to a much smoother latitudinal profile of any magnetospheric current. The distribution of eddy currents in the highly conducting oceans and ocean floors is affected by the latitudinal distribution of the primary currents and consequently leads to different ratios of the vertical and horizontal variation fields near the coastline. Papamastorakis and Haerendel (1974) noticed that the South Indian station Annamalainagar (Fig. 1) happens to be in a position where pure ionospheric currents of short periods (≈ 1 h) lead to zero response in the Z-component, whereas magnetospheric currents create non-vanishing values of Z.

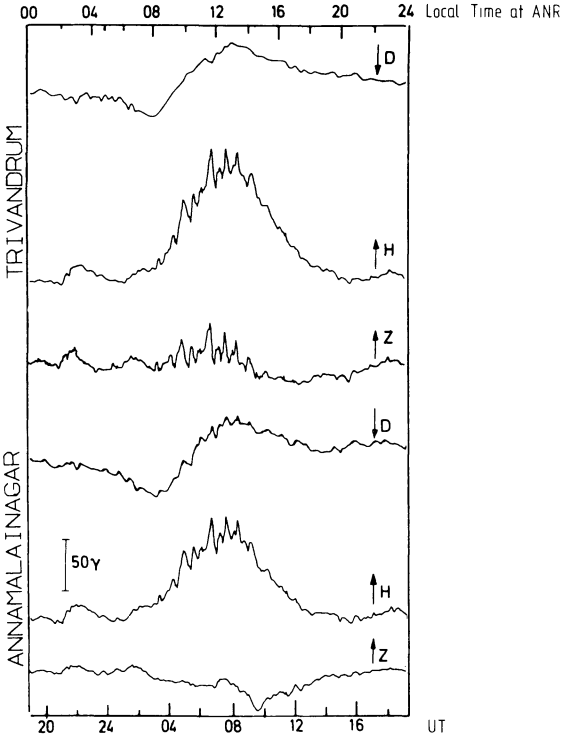
Various aspects of this effect formed the subject of the thesis of Papamastorakis (1975). Its essential results will be summarized in this and two accompanying papers. The present paper will elaborate the effect on the basis of observed short-period variations. After giving a quantitative description of the separation method, we will demonstrate the applicability of the method both to complex individual perturbations and to statistical material of SSC-type variations. Paper II (Papamastorakis and Haerendel, 1983) deals with an analogue model simulating the effect and lending credibility to our interpretation. A third paper will concentrate on actual geophysical applications, namely the separation of the ionospheric and magnetospheric currents for perturbations of the storm sudden commencement (SSC) and DP2 types.

Anomalous Coast Effect at Annamalainagar

The coast effect consists generally of an amplification of the Z-component of magnetic variations over the value expected from the primary current. It is, however, possible to find locations where for certain types of variations the Z-component shows zero response. This is observed at Annamalainagar. Figures 2 and 3 show two examples in comparison with the readings at Trivandrum. One notices that even great excursions of H with periods of the order of 1 h are not accompanied by similarly structured excursions of Z. This applies mainly to daytime perturbations. At night, the behaviour is completely different. Every little excursion, even with amplitudes as low as 2 γ in H, are clearly seen in Z. Further, during daytime, by looking first at the Z-component one is able to find many (normally smaller) perturbations that also appear in H, but the dominant structure of daytime variations is without counterpart in Z. At Trivandrum, the situation is quite uniform, Z and H are exhibiting a classical coast effect.

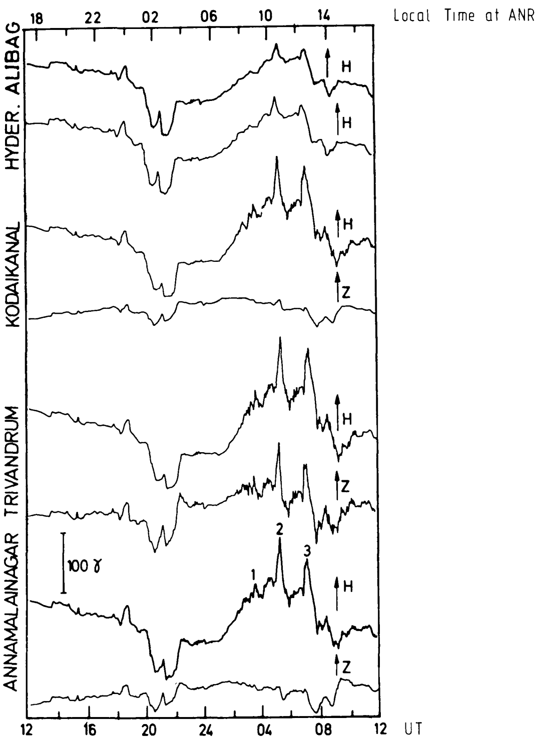
The behavior of the Z-component observed at Annamalainagar is not unique. Kodaikanal is very similar, as can be seen in Fig. 3. However, a small excursion in Z is noticeable for those perturbations that are characterized by $\Delta Z = 0$ at Annamalainagar. Furtermore, the measurement of Z is less sensitive at Kodaikanal. Therefore, we will concentrate on the magnetograms obtained at Annamalainagar, but keep in mind that the interpretation of the effect must allow for its existence at other locations.

Both Annamalainagar and Kodaikanal show a positive ratio $\Delta Z/\Delta H$ for those perturbations which appear in Z. If ΔZ were just the field caused by an inhomogeneous distribution of the primary current, one should expect negative values of $\Delta Z/\Delta H$ for a station north of the dip equator ($Z>0$ downward, $H>0$ northward), since the ionospheric currents are concentrated in the equatorial electrojet. According to Untiedt's (1967) model of the equatorial electrojet $\Delta Z/\Delta H$ of the primary current at these stations would be -0.56 and -0.37, respectively. The actual disappearance of ΔZ for a certain class of perturbations can only be attributed to a cancellation of the fields contributed by the primary and the induced currents. The location of the null in ΔZ can depend not only on the morphology of the good conductors such as ocean, sub-ocean floor, and crustal anomalies, but also on the distribution of the primary currents. Ionospheric currents must necessarily concen-



July 12, 1970

Fig. 2. H-, D-, and Z-components of the magnetic field for 12 July 1970, at Annamalainagar and Trivandrum



April 5-6, 1968

Fig. 3. H- and Z-components for 5 Indian magnetic observatories on 5–6 April 1968

trate along the equator, within a few degrees of latitude, because of the high Cowling conductivity. Magnetospheric currents should be much more uniformly distributed in latitude, wherever they may flow. However, for the latter we also except a symmetry with respect to the equator. Hence, there is little chance to attribute the vanishing ΔZ to a latitudinal shift of the primary current. But we can understand why one type of primary current may lead to $\Delta Z=0$ at certain stations, while another one does not. Annamalainagar and Kodaikanal just happen to fall close to the lines $\Delta Z=0$ for short-term fluctuations in the ionospheric currents which tend to be small at night.

Before we proceed with interpreting this effect we should comment on the tricky question of the baseline from which the short-term fluctuations (periods ~ 1 hour) are measured. An interesting controversy on this subject had arisen 10 years ago between Matsushita and Balsley (1972, 1973) and Nishida (1973) in the context of DP-2 type perturbations. Short-term excursions like those appearing between 08 and 16 LT in Figs. 2 and 3 could either be enhancements of a quiet time current or transient decreases of its intensity. Often, the latter appears to be the case as witnessed by electric field measurements with the Jicamarca radar (Gonzalez et al., 1979). However, since we had no independent means of judging which point of view may be applicable to an individual perturbation we chose the baseline of daytime fluctuations such that ΔH is positive, i.e. in Nishida's sense. At Trivandrum this implies also $\Delta Z>0$. For the quantity of main interest, $\Delta Z/\Delta H$, this does not make much of a difference, except for the period that is attributed to the perturbation. For instance, if we had chosen the zero level of H and Z on the example shown in Fig. 3 in a way that it would meet the peaks designated 1, 2, 3 in H_{ANR}, the perturbations would appear as negative with almost 2 hours period. With our choice of baseline they would be classified as positive with 0.5 hours period. But the ratio $\Delta Z/\Delta H$ would be roughly the same. (Later in this paper we will recognize that the situation in this particular example was even more complex in that two different primary currents exhibited fluctuations of different type with considerable phase shift.) Although the physical interpretation of the perturbation depends on the choice of the zero level, for a discussion of the induction effects it is irrelevant as long as we refer to the same type of primary current and choose the zero lines for H and Z in a consistent fashion. Of course, in general we chose the zero lines in a way that the field after subtraction of the so-defined perturbation appeared to vary much more smoothly. For typical night-time perturbations this means that ΔH was also frequently negative.

We return to the explanation of the two classes of magnetic variations at Annamalainagar (and Kodaikanal), one with $\Delta Z=0$ and the other with $\Delta Z/\Delta H>0$. Papamastorakis and Haerendel (1974) suggested that this was a consequence of the latitudinal distribution of the primary current in combination with the configuration of the (highly conductive) ocean in the Indian sector. The induction at any given site cannot be considered as a local effect when the configuration is as irregular as here. Price (1964) drew attention to so-called *channeled currents* which are induced at some distance from the station under consideration, but whose effect is felt there, because the shape of the conductor leads to formation of eddy currents. The currents induced in the Bay of Bengal by the overhead equatorial electrojet are partially interrupted by the tip of Southern India and Sri Lanka as well as on the eastern side by the Malay Peninsula. Hence a substantial fraction of those currents can only close by being channeled up the east coast of India and southward again in the eastern half of the Bay. Somewhere north of Sri Lanka, the induced currents become divided into a vortex located in the Bay of Bengal and a contribution flowing around the tip of Southern India, partially through the Palk Strait between Sri Lanka and India. This was demonstrated with the help of an analogue model of Papamastorakis (1975), which will be presented in Paper II. Later confirmation of the flow through the Palk Strait was given by Nityananda et al. (1977), Rajaram et al. (1979), and Thakur et al. (1981). Where the currents flow northward along the coast, they create an upward (negative) component of the secondary field which enhances the primary vertical component of positive excursions of the electrojet. On the other hand, they create a downward (positive) Z-component where they are directed southward. Annamalainagar just happens to lie at a point where the negative primary Z-field is exactly balanced by the induced secondary field. However, this cancellation applies only to primary currents flowing in the ionosphere which are necessarily concentrated within $\pm 3°$ from the dip equator.

The different effect of magnetospheric currents arises from their nearly uniform distribution over at least $\pm 10°$ of latitude, i.e. over the whole extent of the Bay of Bengal. Accordingly, the currents induced in this conductor by temporal fluctuations of magnetospheric currents should have a quite different pattern. The current eddy in the northern bay should be smaller. Therefore, Annamalainagar would come more strongly under the influence of currents forced southward along the coast. A positive (negative) Z-component is expected for positive (negative) ΔH not only because of the changed pattern of the induced currents, but also because ΔZ of the primary current should be reduced.

Of course, Annamalainagar is not the only site where this effect exists. Similar points should be found at the west coast of India well north of Trivandrum, at the coasts of Sri Lanka, Somalia, and the Malay Peninsula. Indeed, we noticed already the similarity of Kodaikanal and Annamalainagar. Kodaikanal is about 130 km inland from the point on India's west coast where we would expect $\Delta Z=0$ for ionospheric perturbations (see Paper II). But without more detailed measurements of the variation of ΔZ along a normal to the coast we cannot be sure whether the induced currents which lead to a cancellation of the primary ΔZ are actually flowing in the ocean, or whether, in addition, there are conductivity anomalies in the subcontinent which play a greater role.

The interpretation given above is supported by the diurnal behavior of the two classes of perturbations. The $\Delta Z=0$ variations of typically 1 h period (or less) are found exclusively during daytime when the ionospheric conductivity is high and the electrojet concentration of the currents is known to exist. *At night,* practically all short period perturbations visible in H also appear in Z at Annamalainagar. The concentration of the ionospheric current to $\pm 3°$ latitude still exists at night, but the conductivity is one or two orders of magnitude lower than at midday, whereas the electric fields are of equal magnitude to those during daytime (Kamiyama, 1965; Woodman, 1972; Balsley, 1973). Hence the contribution of ionospheric currents would be almost insignificant at night. Most of the perturbations should be of magnetospheric origin. *During the day* the situation is different. Both ionosphere and magnetosphere contribute. Hence, we observe mixed classes, for which a finite value of ΔZ is found, but with a ratio $\Delta Z/\Delta H$ well below that observed at night. The virtue of this different response to the different primary currents is that any given short period fluctuation of H and Z observed at Annamalainagar can be immediately decomposed into an ionospheric and a magnetospheric contribution without the aid of any other observation. The reason is that the response of the induced currents to primary fields of a given period is linear, so that the effect of simultaneous perturbations of two different current sources would be simply superposed. In order to obtain a quantitative tool for this decomposition, we will now proceed with a statistical analysis of perturbations observed at Annamalainagar and, for comparison, also at Trivandrum.

Statistical Analysis of Magnetic Variations Observed at Annamalainagar and Trivandrum

Figure 4 shows an excellent correlation between the vertical and horizontal components of 17 randomly selected nocturnal events. Since we find in all cases (as well at Trivandrum) that ΔZ and ΔH have the same sign, we work with positive quantities only in our statistical analysis. Instead of ΔH we calculate the full horizontal variation

$$|\Delta \mathbf{H}| = \sqrt{(\Delta H)^2 + (H_0 \cdot \Delta D)^2}. \tag{1}$$

It turns out that ΔD and ΔH are strongly correlated, i.e. the direction of polarization of the horizontal component is rather stable. At Annamalainagar we find:

$$H_0 \cdot \Delta D = \begin{Bmatrix} -0.33 \pm 0.015 \\ -0.24 \pm 0.012 \end{Bmatrix} \cdot \Delta H \tag{2}$$

for nocturnal perturbations of ~1-h period and for daytime perturbations with $\Delta Z = 0$, respectively (see Papamastorakis, 1975). At Trivandrum ΔD is generally much smaller. Accordingly, the difference between $|\Delta H|$ and ΔH is at most 5% and can be neglected. For this reason and because of the need of using different types of indices we will henceforward abbreviate $|\Delta H|$ by ΔH.

The correlations between the vertical and horizontal components which we want to corroborate depend, of course, on frequency. A more careful study should proceed via Fourier analysis of the three orthogonal components of the perturbation vector. We have simplified the task in two respects, (1) by selecting individual perturbations of approximately similar duration (e.g. ~1 h) and reading their overall amplitudes irrespective of their fine structure, and (2) by considering the correlation of two quantities only, ΔZ and ΔH. The rather stable polarization of ΔH, as expressed in Equation 2, justifies the second point and shows that little additional scatter should be introduced into the values of $\Delta Z/\Delta H$ thereby. The first simplification is somewhat unsatisfactory, but appears to be appropriate for a first exploration of the effect.

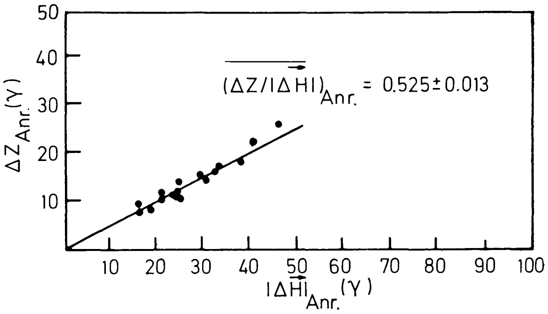


Fig. 4. Correlation between the magnitudes of ΔZ and ΔH for 17 randomly selected nocturnal variations at Annamalainagar. $|\Delta H| \simeq |\Delta H|$

The average ratio, $\langle \Delta Z/\Delta H \rangle$, turns out to be 0.525 ± 0.013 at Annamalainagar. It is found to depend very little on the period for $P \lesssim 1$ h. However, for periods much longer than 1 h, like the daily variation of the Sq-current, ΔZ looks completely different.

We can now use the established ratio

$$m_{ANR} = \langle \Delta Z/\Delta H \rangle_{ANR} \tag{3}$$

for nighttime, i.e. *magnetospheric* perturbations, in order to decompose any observed value ΔH of sufficiently short period into its magnetospheric and ionospheric components, ΔH^m and ΔH^i, by

$$\left(\frac{\Delta H^i}{\Delta H^m}\right)_{ANR} = \frac{m}{\left(\dfrac{\Delta Z}{\Delta H}\right)_{ANR}} - 1. \tag{4}$$

At least, on a statistical basis this equation should be applicable. It is a special case ($i_{ANR} = 0$) of the more general relation:

$$\frac{\Delta H^i}{\Delta H^m} = -\frac{m - \dfrac{\Delta Z}{\Delta H}}{i - \dfrac{\Delta Z}{\Delta H}}, \tag{5}$$

with

$$i = \left\langle \frac{\Delta Z}{\Delta H} \right\rangle, \tag{6}$$

for pure ionospheric perturbations. At Trivandrum, i has a finite value and Equation 5 applies.

Figures 5a and b show the corresponding ratios for Trivandrum. One finds:

$$m_{TRV} = 1.21 \pm 0.026,$$
$$i_{TRV} = 0.95 \pm 0.017.$$

Our first observation is the large value of i_{TRV}. If ΔZ were only due to the inhomogeneity of the primary current, we should have $i_{TRV} \approx +0.1$, as can be seen from Untiedt's (1967) model of the electrojet. Equally, m_{TRV} should nearly vanish. The actual values are a clear signature of the classical coast effect. Furthermore, m_{TRV} is substantially larger than m_{ANR}. This is due to the fact that Annamalainagar is not too far from the line of $\Delta Z = 0$, even for magnetospheric perturbations. According to the results obtained by use of an analogue model (Paper II), the null of ΔZ should be found ≈150 km to the north of Annamalainagar.

All data selected for the determination of the latter coefficient represent perturbations during daytime with $\Delta Z = 0$ at Annamalainagar. Without this tool to recognize pure

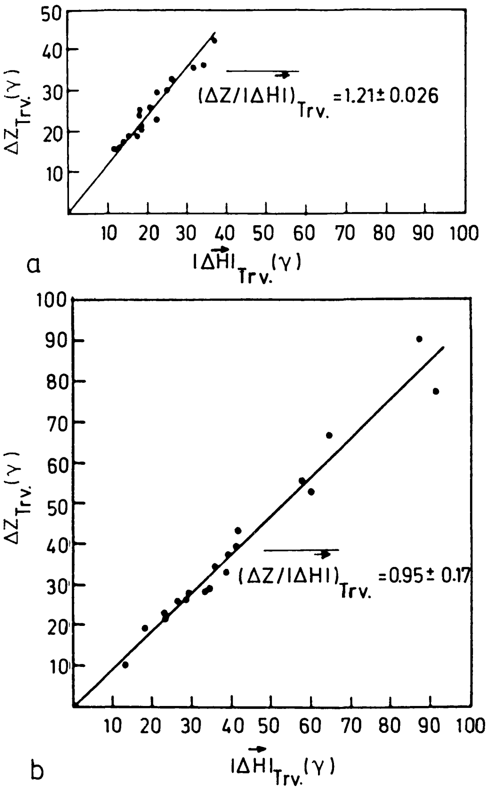


Fig. 5a and b. Correlation between the magnitudes of ΔZ and ΔH at Trivandrum, **a** for the nocturnal variations of Figure 4, **b** for daytime variations with $\frac{\Delta Z}{\Delta H}=0$ at Annamalainagar

ionospheric perturbations, this selection would have been much more difficult.

It is interesting to compare the H-components at Annamalainagar and Trivandrum for the two classes of variations. This is done in Figs. 6a and b. As one should expect from our interpretation of the origin of the anomalous coast effect at Annamalainagar these ratios are not the same for magnetospheric and ionospheric perturbations:

$$h^m=\left\langle\frac{\Delta H_{TRV}}{\Delta H_{ANR}}\right\rangle_m=0.81\pm0.013, \tag{7a}$$

$$h^i=\left\langle\frac{\Delta H_{TRV}}{\Delta H_{ANR}}\right\rangle_i=1.12\pm0.01. \tag{7b}$$

The finding that $h^i>1$ reflects the greater proximity of Trivandrum to the center of the electrojet. The primary current alone would yield $h^i=1.28$ as can be read from Untiedt's (1967) model. The reason for the actually smaller value of h^i must lie in a relatively greater contribution of the induced earth currents to the total horizontal perturbation at Annamalainagar. If this is so, $h^m<h^i$ is no surprise, since the primary field of the wider magnetospheric current should change very little between Trivandrum and Annamalainagar. One of the reasons for the relatively strong induction effect at Annamalainagar may be the channeling of current through the Palk Strait (Fig. 1), as discussed in Paper II.

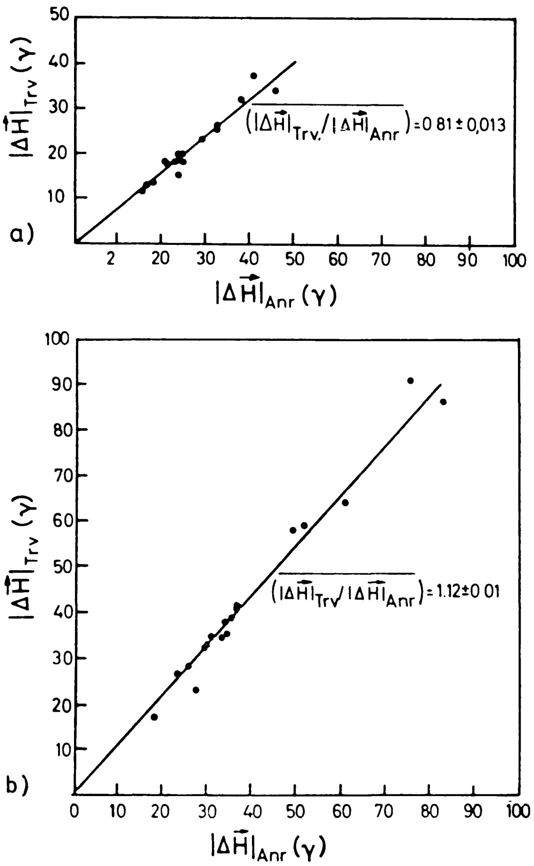


Fig. 6a and b. Correlation of the magnitudes of ΔH_{TRV} and ΔH_{ANR}, **a** for nocturnal variations, **b** for daytime variations with $\frac{\Delta Z}{\Delta H}_{ANR}=0$

There is no easy way to determine what fraction of any observed value of ΔH is due to the primary and what fraction is due to the induced currents. Above the ocean, well away from the coast, the contribution of the latter almost equals the primary field if the periods are sufficiently short. Near the coast, ΔH_{ind} decreases, because of magnetic diffusion through the poorly conducting continent (see Paper II).

It must be mentioned that we find a slight dependence of m_{TRV} on the period which is not observed at Annamalainagar. The above value applies to periods of ≈ 1 h. For 5–10 min fluctuations, as observed in SSCs, we determine

$m_{TRV}=1.31\pm0.018.$

Separation into Magnetospheric and Ionospheric Contributions

The observation of a completely different response of the Z-component at Annamalainagar to magnetospheric and ionospheric primary currents suggests a useful application. Any mixed event should show a $\Delta Z/\Delta H$ smaller than for pure magnetospheric currents, thus allowing us to deduce the ratio of the respective H-components by applying Equation 1. We must, however, realize that m_{ANR} was determined as a statistical average. In any particular event the true value may differ from the statistical average. Furthermore, there may be some dependence on period, although none was obvious for events between 10 min and 1 h. The reason for this is that the skin depth for any period shorter than 1 h is small compared with the relevant linear dimension L_{eff}, which is the geometric mean of ocean depth and scale-length of the primary current (see Paper II). So, the geometric behavior of the fields should be quite similar. This has been verified by solving the induction problem for the case of an alternating band current above an infinite, plane ocean. This leads to the conclusion that for the scale-lengths of the ionospheric and magnetospheric source fields the effects of the induction currents at the ocean surface are nearly independent of the period for periods less than about 1 h and ocean depths of more than 2 km.

Let us now check whether any perturbation of less than ≈ 2 h duration with complex temporal structure can be evaluated by applying Equation 4 to the instantaneous readings of ΔZ and ΔH with constant value of m. We choose one example of a nighttime and hence pure magnetospheric perturbation, namely the period from 20–22 UT on April 5, 1968 (see Fig. 3). Figure 7a is an enlarged plot of the H- and Z-components at Annamalainagar with our choice of baseline from which we reckon ΔH and ΔZ of the perturbation. Figure 7b contains the development of the ratio $\Delta Z/\Delta H$. It is not as constant as one would like it to be, and its average value of 0.45 differs from the statistical result for the amplitudes of 1 h perturbations ($m = 0.525$). For a pure magnetospheric event this deviation and the lack of constancy of $\Delta Z/\Delta H$ may not look so bad. However, small changes of $\Delta Z/\Delta H$ can produce large changes of $\Delta H^i/\Delta H^m$ in Equations 4 when applied in the same fashion to a mixed ionospheric-magnetospheric event. This must be borne in mind, and attention should be focussed on the gross structure of the thus separated contributions of ionospheric and magnetospheric origin rather than on the actual values of ΔH^i and ΔH^m. They may contain substantial errors.

Figure 8 contains an application to an arbitrary mixed event. It was taken from April 6, 1968 (see Fig. 3). Using the dashed baselines and a constant value of $m = \Delta Z/\Delta H$ for magnetospheric perturbations, we can determine $\Delta H^m = m\Delta Z$. The observed readings of ΔH are the sum of ΔH^m and ΔH^i. Hence:

$$\Delta H^i = \Delta H_o - \frac{\Delta Z_{obs}}{m}. \qquad (8)$$

The choice of baseline from which the short-term variations are counted may be questioned as well as the applicability of the statistical value $m = 0.525$ in Equation 8 on an instantaneous basis. However, the minima in Z around 10:30, 12:40 and 13:50 LT indicate clearly the presence of enhanced magnetospheric westward currents which lower the total value of H. A correction for these magnetospheric contributions results in the dotted line in Fig. 8. We see now that the minima in Z, i.e. the maxima of the magnetospheric (probably ring-) current, are closely associated with relative maxima of the ionospheric current, which precede by about 15 min (6 min for the event at 13:50 LT). We must bear in mind, however, that the dotted trace of the H-component in Fig. 8 can only be interpreted in terms of the ionospheric current if the baseline is known. A long-term depression of H (period $\gg 1$ h) due to enhanced ring-current (a magnetic storm was in progress) would not be recognized in Z and would have to be assessed by some other means. By comparing the day under consideration, as shown in Fig. 3, with a less perturbed day as selected for Fig. 2 one gets the impression that the short-term maxima of H on April 6 (Fig. 8) are true enhancements over the Sq-level. The typical amplitude of the Sq variation at Annamalainagar is $\approx 100\,\gamma$ in H, whereas the maxima on April 6 over a baseline conjectured to lie close to or even below the trace of H after 15:00 LT, is of the order of 150 γ. Here we will not dwell on the magnetospheric significance of this result, but use it merely as a demonstration of the usefulness of the anomalous coast effect at Annamalainagar.

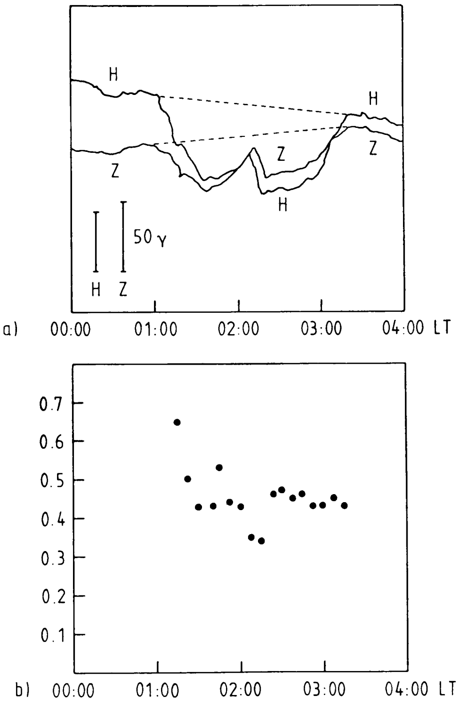


Fig. 7. a Enlarged plot of the H- and Z-components of the negative nocturnal variation shown in Fig. 3 (5 April 1968), **b** ratio $\Delta Z/\Delta H$ for this variation

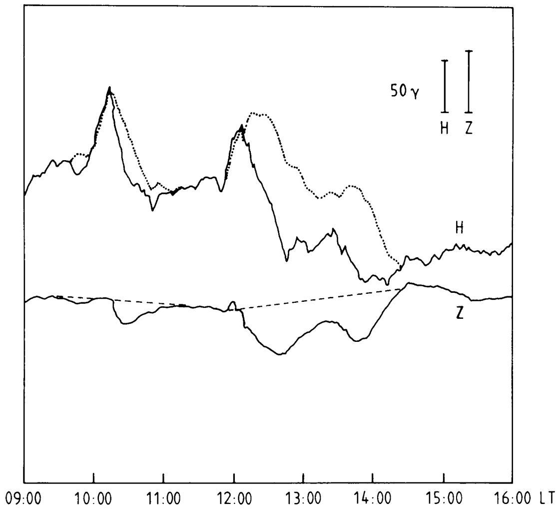


Fig. 8. Determination of the ionospheric part (dotted line) of mixed event observed at Annamalainagar (6 April 1968)

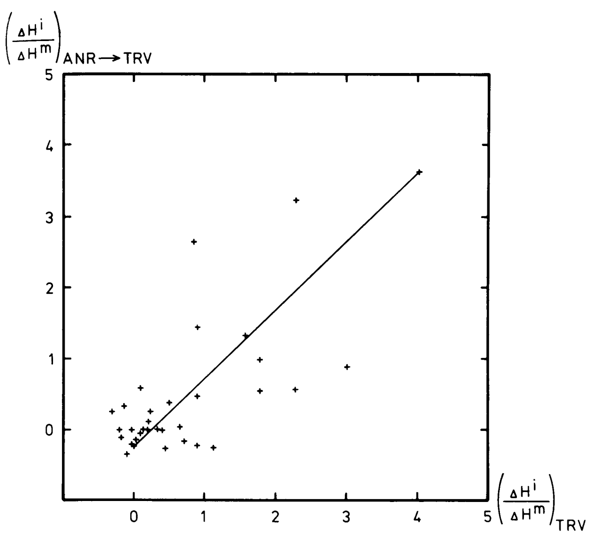


Fig. 9. Correlation between observed ratios $\frac{\Delta H^i}{\Delta H^m}$ at Trivandrum and those calculated by means of Equation 8 from $\Delta H^i/\Delta H^m$ as observed at Annamalainagar for 33 SSC events

Whereas the time-dependent separations of ΔH^m and ΔH^i for one particular event have to be regarded with some caution, statistical applications appear to be more appropriate. We will investigate the consistency of Equations 4, 5 and 7 by comparing the resulting values of $\Delta H^i/\Delta H^m$ as deduced for Trivandrum in two different ways, by the local measurements on the one hand, and by a transfer of the readings at Annamalainagar to Trivandrum by use of the statistical ratios h^m and h^i. The latter is given by:

$$\left(\frac{\Delta H^i}{\Delta H^m}\right)_{ANR\to TRV} = \frac{h^i}{h^m}\left(\frac{\Delta H^i}{\Delta H^m}\right)_{ANR} \qquad (9)$$

with $h^i/h^m = 1.38$ and $(\Delta H^i/\Delta H^m)_{ANR}$ from Equation 4. In a scatter plot of this ratio determined from Equations 9 and 4 respectively, we expect to find a good correlation if our determinations of m, i, h^m, h^i for pure magnetospheric or ionospheric events are also applicable to superpositions of the two.

We selected 33 SSC events from 1968, 1969 and 1970. The result is shown in Fig. 9. In view of the fact large values of $\Delta H^i/\Delta H^m$ are caused by small differences of $\Delta Z/\Delta H$ from the statistical average and must be regarded as rather inaccurate, the agreement of both methods is not bad. The r.m.s. ratio is 0.9 ± 0.03. As a geophysical result we learn from Fig. 9 that the ionospheric currents (and hence the electric fields) are clearly affected by sudden commencements. In a later paper we will deal with this subject in more detail, in particular with the local time dependence of the ionospheric response.

Summary

In this paper we have discussed the origin of the absence of a perturbed Z-component at the Southern Indian station Annamalainagar for fluctuations of a primary current flowing in the ionosphere. This is contrary to the sensitive response found for currents flowing in the magnetosphere. This behavior of Z was attributed in the first case to a cancellation of the contributions of the ionospheric current and the induced earth current (mainly in the waters of the Bay of Bengal). Because of the greater homogeneity of a magnetospheric current, the primary ΔZ is small and the contribution of the induced currents appears in the Z-component. A difference in size of the induced current eddies in the Bay of Bengal may add to the difference in behavior of Z.

The statistical relations between ΔZ and ΔH for pure ionospheric and magnetospheric perturbations of no more than 1 h duration have been evaluated for Trivandrum and Annamalainagar, and the ratios of ΔH at both stations for both types of perturbations have been established. These coefficients enable us to separate the ionospheric and magnetospheric contributions to any arbitrary short-term variation ΔH and thus analyze the ionospheric response to any magnetospheric perturbation. The applicability and potential usefulness have been demonstrated with a few examples.

These findings have been reported by Papamastorakis and Haerendel (1974) and form part of the thesis of the first author (Papamastorakis, 1975). Meanwhile, the discovered effect has found considerable interest and stimulated further investigations (Nityananda et al., 1977; Rajaram et al., 1979; Thakur et al., 1981) so that it appears still useful to present the original material at this late date.

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