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Local time dependence of the response of the equatorial electrojet to DP2 and SI disturbances

I. Papamastorakis*, G. Haerendel, and W. Baumjohann
Max-Planck-Institut für Physik und Astrophysik, Institut für extraterrestrische Physik, D-8046 Garching bei München, Federal Republic of Germany

Abstract. By using a method recently described by Papamastorakis and Haerendel (1983a) the local time dependence of equatorial magnetic field perturbations caused by the response of the equatorial electrojet to DP2 and SI disturbances could be derived from geomagnetic records from the Indian observatory Annamalainagar. For both types of disturbances ΔH and thus the equatorial current shows a pronounced LT-asymmetry with the peak current density observed near 10 LT. This LT-asymmetry of the equatorial current is due to a tilt of the two-vortex electric equipotential pattern (associated with a dawn-to-dusk polar cap field) towards earlier local times at low latitudes. This tilt has its origin in the day-night asymmetry of the ionospheric conductivity distribution.

Key words: Equatorial electrojet – DP2 – SI

Introduction

The magnetic equator region is a suitable laboratory for studying magnetic effects of different origins. The magnetic perturbations of magnetospheric origin (e.g. those caused by ring and magnetopause currents) depend only slightly on latitude and are nearly horizontal whereas those of ionospheric origin are influenced by the strong equatorial enhancement of the Cowling conductivity during daytime hours. The sharp decrease of the Cowling conductivity with increasing dip-latitude leads to a strong inhomogeneity of the "ionospheric" fields over distances of a few hundred km away from the magnetic equator (Untiedt, 1967).

As a consequence of the different scale lengths of ionospheric and magnetospheric field perturbations their induction effects can differ considerably, especially if the underlying conductor is suitably shaped. As Papamastorakis and Haerendel (1983a) showed, the differences between magnetospheric and ionospheric fields are especially pronounced at the geomagnetic observatory Annamalainagar (ANR) which is located under the electrojet at the south-eastern Indian coast. At ANR the external Z component of magnetic field fluctuations of ionospheric origin with periods of about 1 h is almost exactly cancelled by the Z component of the induced currents. Papamastorakis and Haerendel (1983b) demonstrated, by means of an analogue model, that the induced currents which could produce the observed effect for ionospheric field fluctuations flow predominantly in the ocean. But a significant part of the currents is diverted by a conductivity enhancement and flows under the Palk Strait from the Gulf of Bengal to the Indian Ocean (in the case of an eastward electrojet current). Because of their different scale length, magnetospheric fluctuations of similar time period cannot produce a similar effect, so that their ratio $\Delta Z/\Delta H$ at ANR is positive with a magnitude of about 0.5.

The different behaviour of induction fields of different origin at ANR can be used to distinguish fluctuations of ionospheric origin from those of magnetospheric origin, as well as to decompose mixed fluctuations into their ionospheric and magnetospheric parts (Papamastorakis and Haerendel, 1983a). The purpose of this paper is to demonstrate the usefulness of the method in studying geomagnetic effects, especially the local time (LT) dependence of DP2 fluctuations and of ionospheric currents caused by sudden impulses (SIs).

DP2 Disturbances

Nishida (1968) has defined DP2 disturbances as worldwide coherent fluctuations occuring on magnetically slightly disturbed days with a time period of 0.5 to 2 h. DP2 fluctuations are predominantly or fully due to ionospheric currents (Nishida, 1968). The equivalent current system of DP2 is highly asymmetric and consists of two vortices (Fig. 1; after Nishida, 1968). We note that the division line of the two vortices in Fig. 1 is approximately aligned along the 22–10 LT meridian.

DP2 fluctuations are, according to Nishida and Maezawa (1971), positively correlated with the southward component of the IMF: southward turnings of the IMF cause positive magnetic field variations at low latitudes. The worldwide character of the DP2 fluctuations has been subject to further investigations. Onwumechilli et al. (1973) found a positive correlation between magnetic field perturbations in the eastward

* *Permanent address:* University of Crete, Iraklion/Crete, Greece

Offprint requests to: W. Baumjohann

auroral electrojet and in the equatorial electrojet. Carter et al. (1976) observed a positive correlation between H fluctuations in the eastward electrojet and the equatorial electron drift. Patel (1978) concluded from a simultaneous study of the IMF, ionograms and low-latitude geomagnetic field that a northward turning of the IMF leads to a westward electric field in the equatorial ionosphere. Similarly Rastogi et al. (1978) deduced from electron drift measurements that northward variations of the IMF produce a decrease in eastward electrojet current. The aforementioned results led to the conclusion that the DP2 currents are driven by a polar cap dawn-to-dusk electric field and its extension toward mid- and low-latitudes (cf. Nishida, 1978).

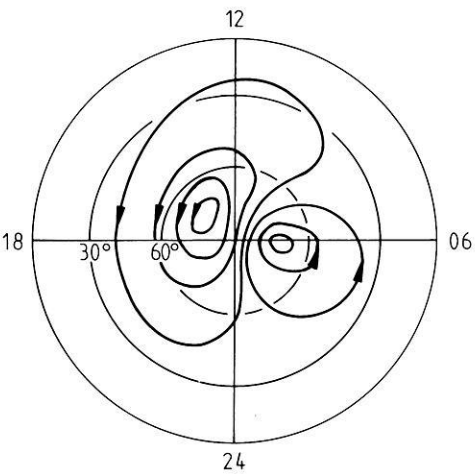

Fig. 1. DP2 equivalent current system after Nishida (1968)

Observations

We will now present observations of magnetic perturbations of ionospheric origin which are consistent with the findings of the above cited authors and lead to conclusions on the local time dependence of DP2 at low latitudes.

Figure 2 shows magnetic records of a moderately disturbed day when a train of perturbations with $\Delta Z = 0$ (numbered by 1, 2, 3) was observed at ANR during daytime. In contrast, fluctuations at night as well as daytime fluctuations other than those numbered show significant ΔZ components. Papamastorakis and Haerendel (1983a) concluded that perturbations with $\Delta Z = 0$ are of purely ionospheric origin. This conclusion is confirmed if one compares the record of ANR with magnetic records from other equatorial (Trivandrum, Kodaikanal) as well as non-equatorial stations (Hyderabad, Alibag) on the Indian peninsula: Fluctuations with $\Delta Z = 0$ are strongly attenuated at stations outside the equatorial region whereas the amplitude of fluctuations with $\Delta Z/\Delta H \neq 0$ shows hardly any change at nighttime (fluctuations of magnetospheric origin) or less significant changes (daytime fluctuations of mixed origin). In passing, we note that the amplitude ratio of ΔH

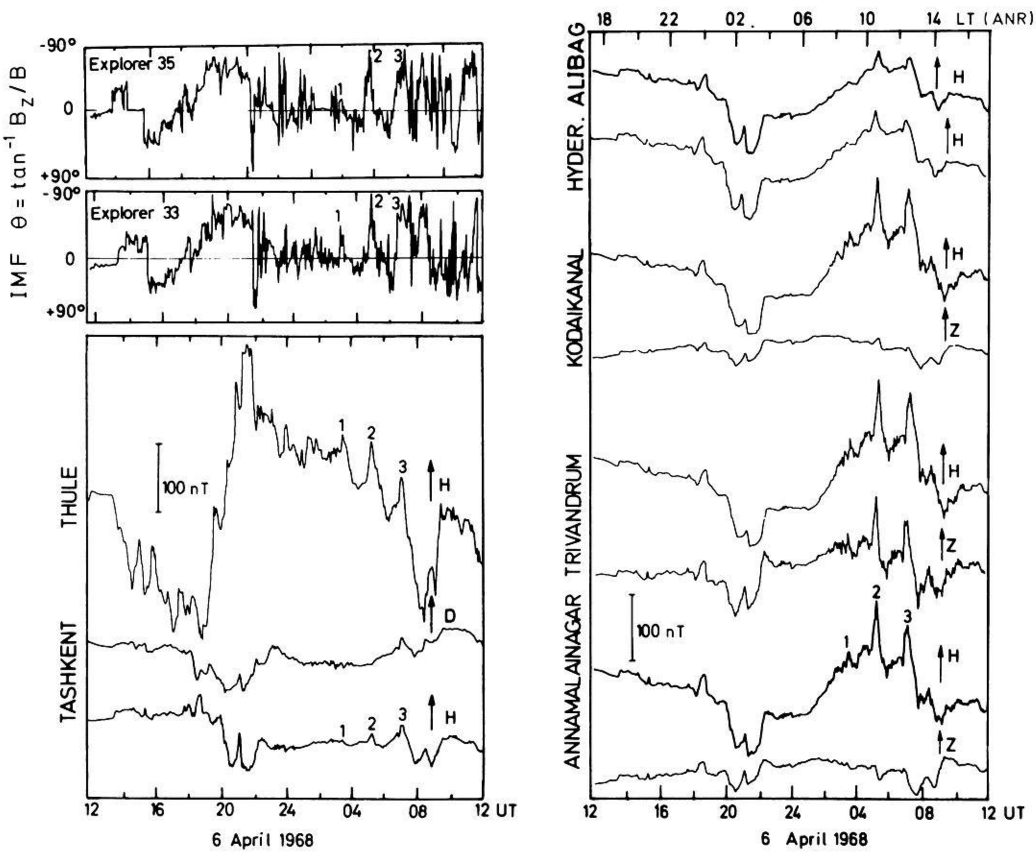

Fig. 2. Magnetic records showing the worldwide coherent occurrence of $\Delta Z = 0$ fluctuations (numbered by 1, 2, 3) and their positive correlation with variations in the angle $\theta = \tan^{-1} B_z/B$ of the IMF

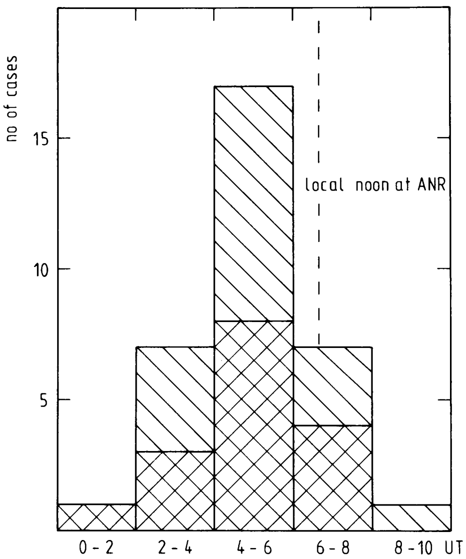

Fig. 3. Histogram showing the local time dependence of the number of $\Delta Z=0$ fluctuations occurring coherently at Annamalainagar and Thule. The fluctuations are divided in two subgroups according to their approximate amplitude at Annamalainagar: Intense ($\Delta H \gtrsim 20$ nT) and moderately intense ($10\,\text{nT} \lesssim \Delta H \lesssim 20$ nT)

at ANR to that at Alibag for the $\Delta Z=0$ fluctuations in Fig. 2 is of the order of 3, a value confirmed by a more thorough analysis of several other $\Delta Z=0$ fluctuations.

The $\Delta Z=0$ fluctuations in Fig. 2 are also correlated with positive fluctuations at the mid-latitude station Tashkent and at the high-latitude station Thule as well as with fluctuations in the north-south component of the IMF recorded by the Explorer 33 and 35 satellites (Fig. 2 left panel). (On the basis of the known positions of both satellites we concluded that the IMF fluctuations should arrive at the earth 8 min later than observed at Explorer 35 and 12 min earlier than observed at Explorer 33; these time-shifts are incorporated in Fig. 2.)

On the basis of Fig. 2 we conclude that the $\Delta Z=0$ perturbations show all the aspects of DP2 variations described by Nishida (1968, 1971) and Nishida and Maezawa (1971). As Fig. 2 indicates $\Delta Z=0$ perturbations seem to lie predominantly in a local time interval which ends at about 13 LT although IMF fluctuations continue to be present during the afternoon hours. Thus it seems that $\Delta Z=0$ perturbations of appreciable ΔH magnitude are not equally distributed in local time. In particular, fluctuations in the afternoon hours are rarely seen. This is demonstrated in Fig. 3 where the number of $\Delta Z=0$ perturbations which correlate with perturbations at the high-latitude station Thule is plotted in the form of a histogram against local time. The perturbations were found by inspection of magnetic records of the whole year 1969. Their amplitudes were estimated as deviations from the quiet time trace at the time before and after their appearance, i.e. in Nishida's (1968) sense.

We have divided the $\Delta Z=0$ fluctuations according to their ΔH-amplitude at ANR into two groups: Those with $\Delta H \gtrsim 20$ nT and those with $10\,\text{nT} \leq \Delta H \leq 20$ nT; (we do not display in Fig. 3 less intense fluctuations because of the difficulty of recognizing them securely as $\Delta Z=0$ fluctuations). In Fig. 3 the asymmetry relative to local noon is very striking and in agreement with DP2 observations at other equatorial stations reported by Nishida and coworkers and summarized by Matsushita and Balsley (1972). Table 1 in their paper demonstrates that on 17 out of 18 days no DP2 events are found after 14 LT. Only in one case are DP2 fluctuations reported between 14 LT and 15 LT. On the other hand DP2 fluctuations are present in the morning hours on most of the days reported.

Therefore, we conclude that a clear asymmetry relative to local noon exists for DP2 fluctuations at the magnetic equator with a maximum around 10 LT.

SI Disturbances

The equatorial enhancement of the SI disturbance field was first noticed by Sugiura (1953). Obayashi and Jacobs (1957) made an extensive study of SIs and suggested that the geomagnetic field variation during a SI must be due partly to a current system flowing in the ionosphere. They inferred an equivalent current system for the SI which consists of two vortices with concentrations over the magnetic pole and at the magnetic equator. It looks very similar to the DP2 current system shown in Fig. 1. In particular, the line dividing the two vortices has the same tilt as in the DP2 current pattern and is approximately aligned along the 22 LT – 10 LT meridian.

Matsushita (1960) plotted the ΔH-amplitude ratio of SIs observed at Huancayo (at magnetic equator) to those at San Juan (at mid-latitudes) as a function of LT. In his Fig. 6 a strong local time dependence is shown with a minimum ratio of 1 at night but a maximum ratio of 10 at 10 LT, i.e. a pronounced local time asymmetry relative to local noon. Nishida (1971) compared magnetic records of the observatories Huancayo (at magnetic equator) and Fuquene (at low-latitudes) and noticed that the equatorial enhancement for the SIs is less than that for the DP2 fluctuations (a ratio of 2 for SIs as compared to 4 for DP2 fluctuations). According to Nishida (1971) this result is consistent with the view that a significant part of the SI field stems from the current flowing in the magnetopause while DP2 fluctuations are predominantly or even fully due to ionospheric current. Rastogi (1976) suggested on the basis of ionospheric measurements with VHF radio waves that the enhancement of ΔH is due to the imposition of an additional electric field onto the equatorial electrojet region. Reddy et al. (1981) concluded from backscatter radar measurements that the daytime SI-related increases in ΔH at electrojet latitudes have a large contribution from an impulsive increase of the eastward electric field and current in the electrojet. The sharp increase of the eastward electric field at the equator again has its origin in (an increase of) the dawn-to-dusk polar cap electric field during the main phase of an SI (cf. Nishida, 1978).

Observations

Figure 4 shows two examples of SIs: one occurred at night (left panel) and the other occurred near local

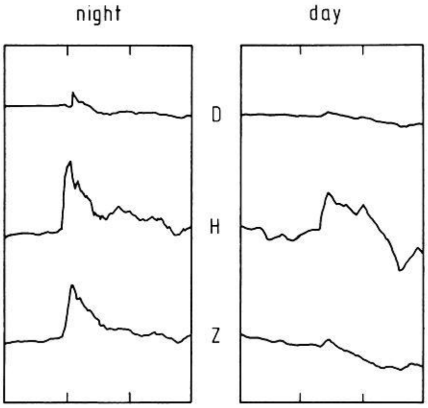

Fig. 4. Examples of SIs at Annamalainagar (the segments cover 3 h) at night and during daytime. Amplitude scales are arbitrary and differ for different components but are equal for both intervals

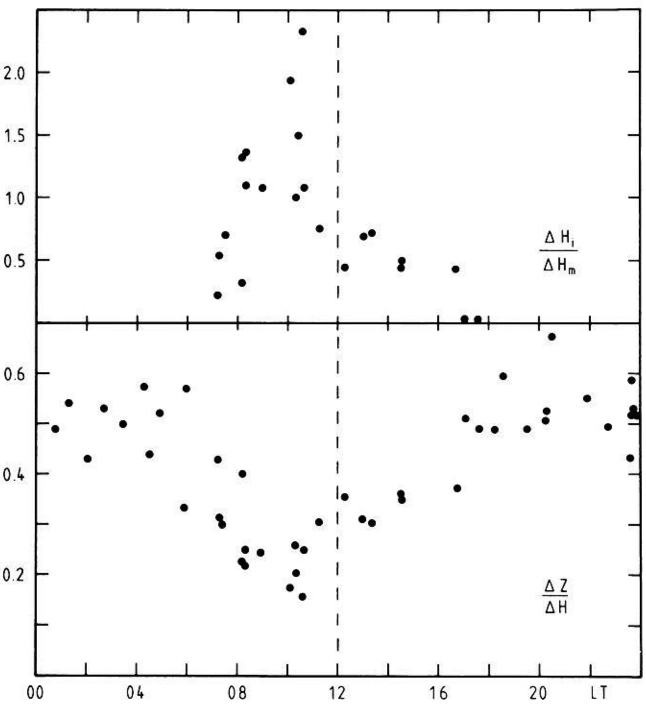

Fig. 5. *Lower panel:* Local time dependence of $\Delta Z/\Delta H$ for 44 SIs observed at Annamalainagar. *Upper panel:* Local time dependence of the calculated amplitude ratio $\Delta H_i/\Delta H_m$ (ionospheric to magnetospheric part) for 21 daytime SIs

noon (right panel). The reduction in the $\Delta Z/\Delta H$ ratio for the daytime event relative to that for the nighttime event is clearly evident. The local time dependence of $\Delta Z/\Delta H$ is shown in the lower panel of Fig. 5, where this ratio is evaluated for 44 SIs observed in the years 1968, 1969, 1970 at ANR and plotted against LT. (ΔH in Fig. 5 is the magnitude of the total horizontal field.) According to Papamastorakis and Haerendel (1983a) we explain the reduction of $\Delta Z/\Delta H$ during daytime as a result of the superposition of a magnetospheric part with $(\Delta Z/\Delta H)_m = m$ which is nearly independent of local time and of an ionospheric part with $(\Delta Z/\Delta H)_i = i$. The mean $\Delta Z/\Delta H$ ratio of the magnetospheric perturbation can be estimated by averaging over the nighttime SIs:

$$m = \left(\overline{\frac{\Delta Z}{\Delta H}}\right)_{\text{night}} = 0.525 \pm 0.017.$$

The ionospheric and magnetospheric parts of the horizontal component of each daytime SI can then be computed using the formula (Papamastorakis and Haerendel, 1983a):

$$\frac{\Delta H_i}{\Delta H_m} = \frac{m - \Delta Z/\Delta H}{\Delta Z/\Delta H} \tag{1}$$

where we have set $i = 0$ while $m = 0.525$ as given above.

In setting $i = 0$ we assumed that $\Delta Z = 0$ fluctuations and the ionospheric part of the SIs produce similar induction effects at ANR despite of their different period of the $\Delta Z = 0$ fluctuations: about 2 h, period of the SIs: about 5 min). The validity of this assumption is supported by the following four facts:

(a) Measurements with the analogue model described by Papamastorakis and Haerendel (1983b) have shown that the positions of $\Delta Z = 0$ remains approximately at the location of ANR for periods of less than 1 h.

(b) Calculations of the induction effect for the case of an infinite plane ocean of finite depth and an overhead band-shaped electrojet have shown that no significant changes for periods less than 1 h and ocean depths greater than 1 km are expected.

(c) The average nighttime $\Delta Z/\Delta H$ ratio is the same for SIs and for long-period (~ 1 h) fluctuations.

(d) The equatorial enhancement of the ionospheric part and thus the source geometry are the same for DP2 and SI disturbances since background equatorial electric field and equatorial conductivity enhancement are independent of the type of disturbance and the additional disturbance electric field is identical for both types of geomagnetic variations (cf. Nishida, 1978).

We conclude that setting $i = 0$ in order to calculate $\Delta H_i/\Delta H_m$ with the above formula is a good approximation. The upper panel of Fig. 5 shows $\Delta H_i/\Delta H_m$ plotted against LT for the 21 events displayed in the lower panel of Fig. 5 which occurred between 0700 LT and 1700 LT. We observe a strong local time asymmetry with a maximum $\Delta H_i/\Delta H_m \approx 2.3$ (or $\Delta H_i/\Delta H \approx 0.7$) at about 10 LT. The mean value for this daytime interval is $\overline{\Delta H_i/\Delta H_m} = 0.88$ (or $\overline{\Delta H_i/\Delta H} = 0.47$), i.e. about 50% of the mean daytime SI perturbation at ANR is of ionospheric origin. Note that even assuming that SI and DP2 produce different induction effect (as proposed by Singh et al., 1982) and thus taking $i \neq 0$ would change only the actual numerical values, but not the LT asymmetry.

We can also calculate the daytime average $\overline{\Delta H_i/\Delta H_m}$ in an independent way if we compare observations at ANR with those at another station. Jain and Sastri (1978) compared the SI amplitudes at ANR and AL (Alibag) for daytime as well as nighttime SIs. The calculated ratios are:

$$\frac{\Delta H_m^{\text{ANR}}}{\Delta H_m^{\text{AL}}} = 1.14 \text{ for nighttime events,}$$

$$\frac{\Delta H_{i+m}^{\mathrm{ANR}}}{\Delta H_{i+m}^{\mathrm{AL}}} = 1.63 \text{ for daytime events.}$$

If we assume that the ratio $\Delta H_i^{\mathrm{ANR}}/\Delta H_i^{\mathrm{AL}}$ is approximately the same for SI and DP2 perturbations, we can take the previously calculated value (cf. Fig. 2) $\Delta H_i^{\mathrm{ANR}}/\Delta H_i^{\mathrm{AL}} \approx 3$. It follows that

$$\frac{\Delta H_{i+m}^{\mathrm{ANR}}}{\Delta H_{i+m}^{\mathrm{AL}}} = \frac{\Delta H_i^{\mathrm{ANR}}/\Delta H_m^{\mathrm{ANR}} + 1}{\frac{\Delta H_i^{\mathrm{AL}}}{\Delta H_i^{\mathrm{ANR}}} \cdot \frac{\Delta H_i^{\mathrm{ANR}}}{\Delta H_m^{\mathrm{ANR}}} + \frac{\Delta H_m^{\mathrm{AL}}}{\Delta H_m^{\mathrm{ANR}}}}. \tag{2}$$

If we solve for $\Delta H_i^{\mathrm{ANR}}/\Delta H_m^{\mathrm{ANR}}$ we get 0.93 in comparison to a ratio of 0.88 found with the first method. Considering the limited amount of data used the agreement of the results from the two methods is excellent.

Discussion

The interesting phenomenon of the pronounced asymmetry relative to local noon at low latitudes which exists for both DP2 as well as SI disturbances seems not to have been discussed explicitly in the literature before now. First of all we ask which part of the SI magnetic perturbation (the ionospheric or the magnetospheric part or both) is responsible for the local time asymmetry around local noon shown in Fig. 5. The magnetospheric part of the SI disturbance is produced by two different current systems: magnetopause currents and symmetric ring current (Nishida, 1978). The perturbation field caused by the magnetopause currents is symmetric with respect to and maximizes at local noon (Mead and Beard, 1964). The perturbation field of the symmetric ring current has obviously no local time dependence. Thus we conclude that both DP2 as well as the ionospheric part of the SI disturbances show similar local time asymmetries around local noon. This conclusion is in accordance with Iyemori and Araki's (1982) suggestion that the equivalent current systems of DP2 and SI should be very similar at low latitudes.

A similar local time asymmetry has been found in high-latitude observations and has been explained as a result of the day-night conductivity asymmetry. For example, Kamide and Akasofu (1981) determined the pattern of equipotential lines over the polar cap during a moderately disturbed period. They noted that the approximate line of symmetry of the pattern is the 1000 MLT–2200 MLT meridian, instead of the expected 1200 MLT–2400 MLT meridian. Nopper and Carovillano (1979) used realistic models of the ionospheric conductivity to determine how the distribution of the electric field in the polar cap ionosphere is controlled by the day-night contrast in conductivity. They found out that for moderately disturbed conditions the line dividing the two vortices of the calculated equipotential pattern is, on the dayside, located approximately along the 10 LT meridian and that this tilt towards earlier local times is caused by the day-night conductivity asymmetry.

Let us now discuss whether the day-night asymmetry of the ionospheric conductivity is also responsible for the LT-asymmetry of the equatorial electrojet's response to DP2 and SI. Since the ionospheric Cowling conductivity at the equator has its maximum around local noon the maximum eastward current near 10 LT must be caused by a maximum in the eastward electric field imposed onto the equatorial ionosphere by the DP2 or SI disturbance around 10 LT.

The electric field imposed by DP2 or (the main phase of) SI disturbances onto the polar ionosphere is dawn-to-dusk directed in both cases (cf. Nishida, 1978) and thus does not have an LT-asymmetry. However, the associated low-latitude electric field pattern depends strongly on the ionospheric conductivity distribution. Blanc (1983) has most recently calculated the equatorial electric field caused by a dawn-to-dusk directed electric field at high latitudes (modelled by specifying a corresponding electric potential along the 75° latitude circle) for a realistic ionospheric conductivity distribution including a day-night asymmetry and, in fact, he found the electric equipotential lines are tilted towards earlier local times at low latitudes. Blanc's (1983) Fig. 14 clearly shows that the equatorial electric field associated with a dawn-to-dusk directed polar electric field is eastward directed and has its maximum in the forenoon hours. Thus we may conclude that the 10 LT equatorial current maximum during DP2 disturbances and the main phases of SIs is a natural consequence of a low-latitude electric field LT-asymmetry caused by the ionospheric conductivity decrease toward the nightside.

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