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Viking: FIRST RESULTS

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Abstract

After a brief description of the electric field instrument some features of the measured electric field are illustrated by specific examples. Overviews are given of two satellite passes over the northern auroral oval and polar cap, one noon-midnight and one evening-morning pass. An example of a Pi2 pulsation event is given and interpreted in terms of a damped resonant oscillation, probably caused by a sudden impulse. A ULF wave is shown, which due to the high Alfvén velocity can be seen only in the electric field. An auroral arc crossing is presented, where the electric and magnetic field data are consistent with an upward directed magnetic-field aligned electric field associated with an upward Birkeland current.

Introduction

The design of the electric field instrument (V1) on Viking, which is described in a separate paper (Block et al., 1987) is similar to that on GEOS 2 (Pedersen et al., 1984). It consists of six spherical sensors with 10 cm diameter. Four of them are mounted at the ends of 40 meter long wire booms in the satellite spin plane, (radial probes) and two on 4 meter long rigid booms parallel to the spin axis (axial probes). The spin period is 20 seconds.

The main measured parameters are the three potential differences between opposite probes, corresponding to the two radial and the axial field components. The basic sampling rate is 53.3 samples/second, which is the same as for the magnetic field instrument (Potemra et al., 1987). With the two radial probe pairs the electric field vector in the spin plane is thus measured with a resolution of about 20 ms. Also measured is the averaged potential of selected probes with respect to satellite ground, which is called "floating ground potential", or V_{fg} . This is done with a somewhat lower time resolution.

V_{fg} depends on the electron density and more weakly on the electron temperature (Lindqvist, 1983). It therefore gives a crude indication of the ambient density. The normal case with negative V_{fg} corresponds to positive satellite potential with respect to the plasma. Positive V_{fg} occurs only in unusually dense plasmas. A rough calibration of V_{fg} for electron density has been made by comparison with wave data and Langmuir probe sweeps. Since V_{fg} depends weakly also on electron temperature, the density scale is uncertain by a factor of 2-3. More detailed comparisons are planned for a future publication.

The coordinate system to be used for electric and magnetic field vectors in this paper is defined as follows: Axis 1 is along the projection of the magnetic field onto the spin plane. Axis 2 is in the spin plane and transverse to the magnetic field. Axis 3 which completes the right-handed orthogonal system is along the

spin axis. Most of the time axis 2 was nearly parallel or antiparallel to the local tangent of the orbit.

As the data analysis is still in an early stage, no comprehensive statistical surveys have yet been made, but typical features of the measured electric field will be illustrated by individual examples.

Overview of two selected orbits

Figure 1 shows data (in the frame of reference of the spinning spacecraft) from a typical noon midnight pass (orbit 1055) covering altitude (Alt), invariant latitude (ILat) and satellite magnetic local time (MLT) as given at the bottom of the Figure.

In this case Viking crossed the dayside auroral oval and cleft between 15.55 and 16.13 UT. Although not very conspicuous in this particular passage, relative enhancement of the density in the cleft is a common feature (with V_{fg} often approaching zero).

As Viking had its apogee on the dayside, the highest altitude measurements have been made above the polar cleft and dayside auroral oval. Typical altitudes over the dayside oval and cleft have been 11,000 - 13,500 km and 6,000 - 9,000 km over the nightside. A surprising feature of the data is that strong, spiky electric fields are very prevalent in the high altitude cleft region. These fields are sometimes very similar to the "electrostatic shocks" observed at lower altitudes by the S3-3 satellite (Mozer et al., 1977) but usually more extended and more complex. Although cases of simple paired structures occur (and will be discussed below), the spiky electric fields are usually irregular. On S3-3 (apogee 8,000 km), the occurrence of these fields were found to vary rapidly with altitude, but within the range covered by S3-3 there was no obvious difference in width and field strength between day and night. The fine structure of the spiky electric fields is illustrated in the insert in the upper panel of Figure 1. Although there is sometimes a slight preference for variation on a time scale of

about 1 or 2 sec (corresponding to a few km), the structure has a wide range of scales extending beyond the resolution of the electric field experiment.

The strong spiky electric fields have no generally valid positive or negative correlation with density variations. Whereas in the nightside auroral oval there is a tendency for strong electric fields to be associated with density depletions, the opposite case is not uncommon on the dayside. The complexities of these correlations remain to be investigated.

In the polar cap (16.13 - 16.47 UT) the electric field had a fairly constant value mostly due to $\underline{v} \times \underline{B}$ ($\underline{v}$ being the satellite velocity).

The density is usually quite low in the polar cap, often less than 1 cm^{-3} . Deep density dropouts, such as the one at 16.41 UT, are fairly common in the polar cap. They are also seen in the wave data. The cause is unknown. It may be speculated that they are related to subvisual F-region arcs associated with velocity shears and with enhanced F-region ionization (Carlson et al., 1984) but depleted electron density at the high Viking altitude (Block and Fälthammar, 1968). Preliminary studies of the electric field direction indicate several reversals in agreement with this. Field-aligned currents should be expected at the reversals, but they were too weak (less than 1 A/m^2 in the ionosphere) to be seen in the magnetic field data.

The nightside auroral oval is encountered at 16.47 - 16.54 UT. It was in this case unusually thin and quiet. The steady increase in the electric field south of the oval is due primarily to increasing $\underline{v} \times \underline{B}$.

The plasmopause was traversed at 17.01 - 17.03, as indicated by the sharp rise in plasma density (V_{fg}).

An overview of an evening-morning pass (orbit 257) is shown in Figure 2. As seen from the top two panels, the morning- and dayside oval is wider and much more dynamic, with larger electric fields, than the evening- and nightside. This is typical for quiet and moderately active conditions. However, because of the previously discussed characteristics of the orbit, we are comparing the morning oval at high altitude with the evening oval at lower altitude.

The polar cap is dominated by an electric field of a few mV/m, directed dawn-dusk, with possibly one or a few sun-aligned arcs on the morning side. The voltage across the polar cap (third panel) was about 70 kV. The density (bottom panel, V_{fg}) is much lower in the morning side oval than anywhere else along this orbit, consistent with the higher altitude.

Auroral oval crossings

The pair of oppositely directed large amplitude spikes in the E_2 component (coordinate system defined above) near the southern edge of the evening side auroral oval, observed on orbit 257, is shown in more detail in the insert of Figure 2. The short duration fields are directed towards the reversal between them, northward on the south side and southward on the north side. It looks like a clear signature of an isolated auroral arc, apparently the southernmost one, possibly with U-shaped equipotential lines in meridional cross-sections. Details of this arc will be discussed later.

In the main part of the oval (14.01 - 14.04 UT) there are a large number of reversals in E_2 . The field variations in this region are extremely complicated and no interpretations will be attempted here.

The morning side oval traversed at high altitude was not only much wider, but had also larger and faster fluctuating electric fields, and frequently much lower electron densities than the evening oval observed at lower altitude. This was typical of the

relatively quiet conditions that prevailed during this orbit ($K_p = 3$ at 12-15 UT and 2+ at 15-18 UT).

Waves and pulsations

Waves with frequencies from a few mHz to a few Hz are frequently observed. There are cases where both the electric and magnetic fields of the waves are observed.

However, an important finding is that quite often the wave shows up very clearly in the electric field data but only barely, or not at all, in the magnetic field data. The reason for this is that along the Viking orbit the density is often so low (less than 20 cm^{-3}) that (with the rather strong magnetic field about 2000 nT) it corresponds to very high Alfvén velocities, 10,000 km/s or more. It follows that even with easily observable electric fields of several mV/m, the magnetic fields of the waves can be at or below the bit resolution (at best 1 nT) of the magnetic measurements. In other words, electric field measurements in this region of space widens the range of observable MHD waves by about a power of ten.

Two events will be discussed. The first event is a damped Pi2 pulsation where both the electric and magnetic fields were strong (Figure 3). It had a period of 150 seconds. The electric and magnetic fields were almost 90° out of phase and had amplitudes of 15 mV/m and 30 nT, respectively. The numbers are reconcilable with a magnetic field line resonance at the fundamental mode. During the pulsation the period appears to decrease slightly. This is not surprising since the invariant latitude decreases during the pulsation and therefore also the magnetic field line length.

In addition to the atypical local time of this Pi2 observation we may note that there was no appreciable substorm activity at the time. The source may in this case have been a sudden impulse, which caused similar pulsations observed by groundbased magnetometers 4 to 5 hours of local time west of the Viking

field line footpoint with a period of about 5 minutes (T. Bösinger, private communication).

The second event to be discussed occurred in orbit 292. The data are shown in Figure 4. The frequency is about 0.5 - 0.6 Hz, which shows up as a clear peak in the frequency spectrum of the electric field component E_2 (transverse to $\underline{B}$). This is a case where the magnetic field of the wave is less than the 1 nT bit resolution and thus not measurable. Assuming negligible parallel electric field, the polarization was found to be linear, with the electric field vector of the wave approximately in the east-west direction.

The variations in amplitude with a period of about 16 seconds (Figure 4) are similar to those seen in Pc1 pearl events (Kokubun, 1970; Gendrin et al., 1978). Rauch and Roux (1982) have shown that observations at geosynchronous orbit are consistent with wave packets bouncing between mirrors off the equator. Our observations are consistent with their model, assuming that the mirrors are located above Viking and that the waves are leaking or tunneling through the mirror down to the ionosphere, as proposed by Perraut et al. (1984).

Parallel electric fields

Magnetic field-aligned electric fields on auroral field lines have earlier been observed on S3-3, as reported by Mozer et al. (1977, 1980) and Temerin et al. (1982). A systematic search for such fields in the Viking data has recently started and two cases will be discussed here.

Figure 5 shows data from the southernmost arc observed on orbit 257 (briefly mentioned earlier) on an expanded time scale using the full 20 ms resolution. The angle ϕ between the magnetic field and the spin plane was only 4.5 degrees. Thus the electric field component E_1 (defined earlier) is not quite but very nearly parallel to the magnetic field. A finite value of E_1 can result either from (1) a magnetic-field aligned electric field

or from (2) an electric field transverse to the magnetic field and to the coordinate axis no 2, i.e. roughly east-west (or a combination of both). However, the latter contributes only in the proportion $\sin \phi$ which is about 0.08. To explain the measured E_1 by transverse electric fields only would therefore require not only that the east-west electric field were stronger than the north-south field (second panel in Figure 5) but also that it had rapid variations (ranging from -250 to +300 mV/m). From S3-3 results it is known that in this kind of structure the east-west component is typically weaker and less variable than the north-south component, as is also expected since arcs are extended in the east-west direction. Thus the only tenable interpretation is that in this case E_1 mainly represents a magnetic-field aligned electric field.

The interpretation in terms of a parallel field, $E_{\parallel}$, enables us to construct a self-consistent picture using existing models of auroral arcs. E_1 is negative (directed upward) during an interval of about 1.5 seconds centered at the E_2 reversal, consistent with U-shaped equipotential surfaces. The main upward electric field ($-E_1$) around 13.58.26 UT coincides with maximum slope of B_3 , corresponding to an upward current of $5 \mu\text{A/m}^2$, or about $50 \mu\text{A/m}^2$ in the ionosphere. These maxima are located about 1.5 - 2 km south of the E_2 reversal. That may be explained by a slightly oblique crossing over the arc being associated with a rotational, rather than a tangential, discontinuity in the perpendicular electric field (Atkinson, 1982; Block, 1983). Another possible explanation is that since $j_{\parallel} = \nabla \cdot (\Sigma \underline{E}_{\perp})$, where Σ is the ionospheric conductivity tensor, a displacement will occur if the maximum divergence of the transverse electric field does not coincide with the maximum conductivity gradient which is often the case.

The size of the entire structure is some 30-40 km in the north-south direction (only part of which is seen in Figure 5) and presumably much longer in the east-west direction. The potential drop below the satellite should equal the integrated potential on each side of the reversal, which is about 1 kV.

Assuming that $E_{\parallel}$ is of the order of 10 mV/m also below the satellite, the structure should extend some 100 km downward. In the collisionless magnetic-mirror controlled plasma around Viking the concept of a locally defined conductivity is not very useful. However, under certain assumptions a conductance can be defined, and its value is typically $3 (\mu\text{A}/\text{m}^2)/\text{kV}$ referred to the ionospheric level (Fälthammar, 1977). In order to drive a Birkeland current of the observed intensity ($50 \mu\text{A}/\text{m}^2$ at ionospheric level) through the magnetic mirror would then require a potential drop of well above 10 kV. If roughly evenly distributed, it would have to extend more than 1000 km above Viking.

Other signatures in our data that look like possible candidates for parallel electric fields, have been found. As an example, we may consider the evening side oval crossing in orbit 257, shown in Figure 2. North of the isolated arc discussed above, the angle between the magnetic field and the spin plane decreased to only 0.8 degrees near the northern edge of the oval. It means that some large spikes in $E_{\perp}$, if real, would correspond to either $E_{\perp}$ greater than 1,000 mV/m or $E_{\parallel} = 20$ to 30 mV/m, or some combination of $E_{\perp}$ and $E_{\parallel}$. However, more detailed analysis is required before a parallel electric field can be positively identified in this and many other events.

If the larger electric fields commonly observed on the dayside are an effect of higher altitude, it means that substantial field aligned potential drops must exist at these altitudes, since otherwise the perpendicular fields would decrease with increasing altitude.

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Figure captions

Fig. 1. Overview of the noon-midnight orbit 1055. The upper panel shows the spin plane electric field as measured by probes 3 and 4. (In the frame of the spinning satellite a steady electric field is represented by an unmodulated sine wave.) The lower panel shows the floating ground potential V_{fg} with a rough electron density scale at the right.

Fig. 2. Overview of the evening-morning orbit 257. The format of the top and bottom panels is the same as in Figure 1. The second panel shows the corresponding despun electric field component E_2 , which is transverse to the magnetic field and nearly parallel to the local orbit direction (positive toward dusk). The third panel shows the variation of electric potential as obtained by integration of the electric field along the orbit.

Fig. 3. Pi2 pulsations observed on orbit 375. The upper panel shows the electric field component approximately along the orbit and the lower panel the magnetic field component that is transverse to it and approximately transverse to the average magnetic field.

Fig. 4. Electric field of a ULF wave observed on orbit 292. The upper panel shows the electric field component approximately along the orbit and the lower panel its frequency spectrum.

Fig. 5. Details of an evening-side auroral arc observed on orbit 257. The electric field component E_1 (top panel) is in this case within 4.5 degrees from the magnetic field. The change of sign in E_2 (middle panel) represents a reversal of the transverse electric field, which nearly coincides with an upward Birkeland current revealed by the steep change of the magnetic field component B_3 (bottom panel).

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

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Key words: Auroral oval, Birkeland currents, Double probe measurements, Electric field, Ionosphere, Magnetosphere, Magnetic pulsations, Pi2, Polar cap, ULF waves, Viking.