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Simultaneous Electric Field Measurements Near $L = 4$ From Conjugate Balloons and Whistlers

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Electric field measurements have been obtained simultaneously in conjugate ionospheres by balloons near $L = 4$ and near the equator by analyses of the motion of whistler ducts near $L = 4$ and $L = 2.7$. The observations were conducted from Siple, Antarctica, and Rouyn, Canada, in December 1969. The westward ionospheric electric field components measured by the two conjugate balloons are in agreement with each other, as are the westward equatorial measurements on the two ducts. The equatorial data agree in general with the mapped ionospheric results, although the equatorial measurements are smaller in average magnitude. The southward ionospheric electric field components in the conjugate ionospheres do not bear any simple resemblance to each other.

In December 1969 a conjugate point experiment at $L \sim 4$ was conducted by using balloon-borne electric field detectors (University of California at Berkeley) and a ground-based VLF receiver (Stanford University). The intention was to investigate the conjugacy of magnetospheric electric fields as determined from balloons and to compare results on the east-west component of electric fields obtained from balloons [e.g., *Mozer and Serlin,* 1969; *Mozer,* 1971] with results from the whistler method of tracking the cross L motions of field-aligned whistler paths [e.g., *Carpenter et al.,* 1972]. The limited number of acquired data exhibit both encouraging and puzzling aspects. The purpose of this brief report is to describe the experimental results.

Balloons were launched from Siple, Antarctica ($L \sim 4$, 76°S, 84°W), and Rouyn, Canada ($L \sim 4$, 48°N, 79°W), on December 7 and December 15, 1969. Rouyn is about 500 km west of the calculated conjugate of Siple. It was expected that the strong winter winds at balloon altitudes would carry the northern hemisphere balloons over the conjugate point in a few hours. However, the float altitude winds were anomalous during both flights, so that the northern hemisphere balloons drifted southeast and were 400–500 km from the calculated conjugate point throughout both flights.

In the austral summer, whistler activity near Siple is limited by a number of factors, including absorption in the overlying sunlit ionosphere and a seasonal low in thunderstorm activity in the conjugate region. Fortunately, whistler data sufficient for determination of cross L drifts were available during the period ~0730–0900 UT on December 7, 1969 (near ~03 MLT). Two paths were tracked, one near $L = 4$ and the other at $L \sim 2.7$. In the whistler experiment, path longitude is not determined explicitly but under austral summer conditions may be expected to be within $\sim\pm 10°$ of the observing station. This range is somewhat smaller than the $\pm 15°$ estimated for austral winter conditions [*Carpenter,* 1966].

In Figure 1, 15-min averages of the components of the ionospheric electric field perpendicular to the magnetic field in a geomagnetic rotating frame of reference are presented for data obtained from the pair of balloons flown on December 7, 1969. The magnitudes of the error bars were estimated from differences between two independent field measurements on each balloon (the December 15 data are not presented owing to a lack of suitable whistler data and to the degradation of the Siple balloon data by a timer malfunction that prevented the transmitter antenna from deploying).

The interval illustrated in Figure 1 was one of quieting following a day of moderate disturbance. On the previous day, Kp (the sign being ignored) was 44333333, whereas on December 7 it was 11121112. The whistler data showed that the plasmasphere extended to at least $L = 4$ near 0800 UT on December 7. From a Langmuir probe on Isis 1, *Brace and Theis* [1974] report the night side plasmapause to have been near $L = 4$ near the time of Figure 1. It is thus possible that the Siple balloon was near the plasmapause, whereas the southerly motion of the Rouyn balloon probably caused the northern hemisphere measurements to be made well within the plasmasphere.

Figure 1 shows general agreement between the westward electric field components measured beneath the conjugate ionospheres. In contrast, the north-south components, which in a conjugate mapping relation would be expected to be anticorrelated, do not show a clear relationship.

Figure 2 compares 30-min averages of the balloon results on the east-west electric field with similar averages of the magnetospheric field deduced from whistlers propagating near $L = 4$ and near $L = 2.7$. The error bars on the whistler data reflect measurement error. The scale appropriate to the balloon data is at the left; the one for the whistler data is at the right. The two scales are related by a factor of 8, which is the mapping factor at $L = 4$ between the ionosphere and the equatorial plane for the east-west electric field, a dipole geomagnetic field and no parallel electric field being assumed [*Mozer,* 1970]. Between 0730 and 0800 UT the equatorial data indicate a near-zero field, whereas the balloon data show an eastward field of about 6 mV/m at ionospheric heights. Following about 0800 UT both experiments show the field to be eastward, and there is a relatively good agreement on magnitude. Averaged over the entire 0730–0900 period, the two sets of data both show an eastward direction, but the balloon results mapped to the equator are larger in magnitude by a factor of about 2.

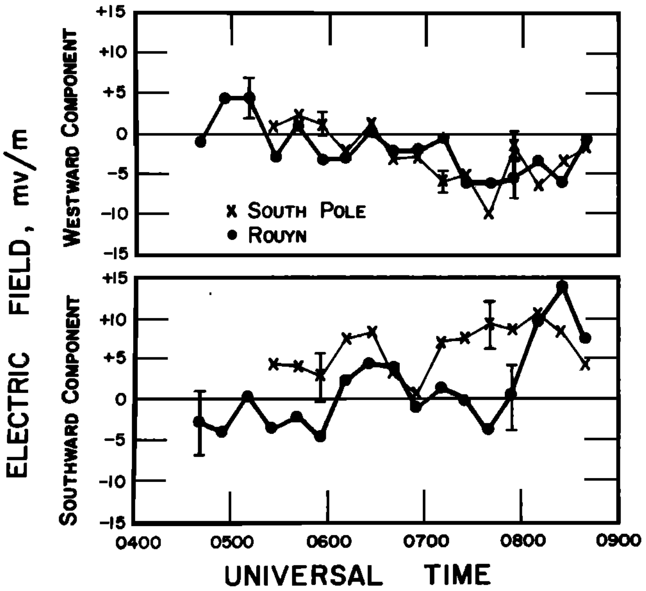

Fig. 1. Fifteen-min averages of ionospheric electric fields measured simultaneously on balloons at near-conjugate locations at $L \sim 4$ on December 7, 1969.

DISCUSSION

Regarding Figure 1, the apparent lack of agreement in the north-south components in the presence of substantial agreement in the east-west fields may possibly be due to one or both of the following reasons:

1. There are relatively large error bars on the north-south measurements, so that definitive conclusions on the relations of the two sets of data cannot be reached.

2. The northern hemisphere balloon drifted to lower latitudes and was 400–500 km from the conjugate to Siple. The lack of anticorrelation of the north-south fields may be due to spatial variations in the ionospheric electric fields, which in previous balloon measurements have been found to possess scale sizes less than 100 km [*Mozer and Manka*, 1971]. From this point of view, the correlation between the eastward field measurements may be fortuitous. On the other hand, the eastward fields may have a larger correlation scale length than the southward components do. A relatively large scale size in L space is suggested by the VLF measurements of Figure 2. The eastward field may be partly the result of a dynamo process in the ionosphere, or it may have penetrated the plasmapause more efficiently from outside than the north-south field, which is more nearly perpendicular to the plasmapause density gradients. As was noted above, the Siple balloon may have been near the plasmapause and subject to spatial variations in the north-south electric field associated therewith.

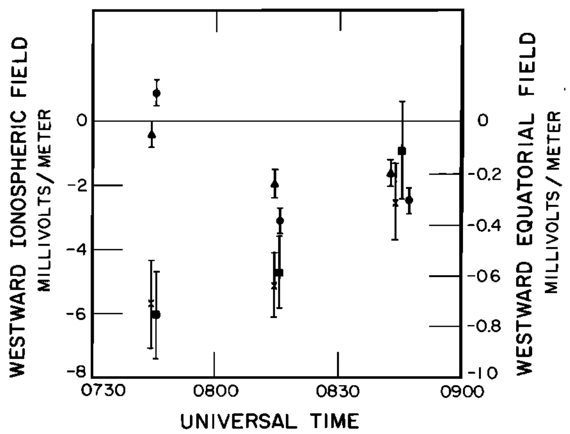

Fig. 2. Thirty-min averages of the simultaneous balloon and VLF measurements of westward electric fields on December 7, 1969. The circles denote VLF equatorial data at $L = 4$, triangles denote VLF equatorial data at $L = 2.7$, squares denote northern ionosphere balloon data, and crosses denote southern ionosphere balloon data.

Regarding the comparisons of east-west fields in Figure 2, the generally eastward orientation of the fields between 0730 and 0900 is consistent with data previously reported for the aftermath of substorms [*Carpenter et al.*, 1972] or as a regular feature of quieting or quiet conditions [*Carpenter and Stone*, 1968]. In this case there was no known large-scale substorm activity as evidenced in mid- to low-latitude magnetic records, and the behavior is tentatively considered as part of a quiet time pattern. As was remarked above, it is possible that part of the eastward field near 0800 UT is due to a dynamo effect, since the inferred fields near $L = 2.7$ are comparable to those near $L = 4$.

The observed general tendency for the mapped balloon westward field magnitudes to exceed the VLF equatorial values has also been suggested by statistical comparisons [*Carpenter et al.*, 1972] and by 5 hours of previous direct comparisons [*Mozer and Carpenter*, 1973]. The significance and interpretation of this tendency is not clear.

For the 1½ hours of compared data there is agreement between the balloon and VLF values in the average direction of the east-west electric field and agreement within a factor of about 2 on its magnitude. There is also promising agreement in the general trend of the east-west field as seen from roughly conjugate balloons. There is now increased experimental activity at $L = 4$ at Siple station and its conjugate Roberval, Canada. We hope to use these stations as a basis for further comparisons of the balloon and VLF techniques and in general for studies of the evidently complex electric field phenomena that occur near the plasmapause.

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