

TWO SUBSTORM STUDIES OF RELATIONS BETWEEN WESTWARD
ELECTRIC FIELDS IN THE OUTER PLASMASPHERE, AURORAL
ACTIVITY, AND GEOMAGNETIC PERTURBATIONS

by

D. L. Carpenter
Radioscience Laboratory
Stanford University
Stanford, California 94305

and

Syun-I. Akasofu
Geophysical Institute
University of Alaska
College, Alaska 99701

CASE
FOR
FILE

ABSTRACT

In two case studies of magnetospheric substorms, temporal variations of the westward component of magnetospheric convection electric field in the outer plasmasphere were compared to auroral activity near $L = 7$ and to variations in the geomagnetic field at middle and high latitudes. The substorms occurred on July 29, 1965 near 0530 UT and on August 20, 1965 near 0730 UT. The results on westward electric field E_w were obtained by the whistler method using data from Eights, Antarctica ($L \sim 4$). All sky camera records were obtained from Byrd, Antarctica, ($L \sim 7$), located within about 1 hour of Eights in magnetic local time. It was found that E_w within the outer plasmasphere increased rapidly to substorm levels about the time of auroral expansion at nearby longitudes. This behavior differs from results on E_w from balloons, which show E_w reaching enhanced levels prior to the expansion. A close temporal relation was found between the rapid, substorm associated increases in E_w and a well known type of nightside geomagnetic perturbation. Particularly well defined was the correlation of E_w rise and a large deviation of the D component at middle latitudes.

I. INTRODUCTION

Much has recently been learned about magnetospheric convection electric fields (e.g. Maynard [1971], Mozer [1971], Heppner [1972], Haerendel [1972], Kaufman and Gurnett [1972]), and it is now possible to make detailed comparisons between these fields and certain related phenomena. In a recent presentation of several case studies, preliminary comparisons were made between magnetospheric east-west electric fields deduced from whistlers, the interplanetary magnetic field orientation, and substorm bay events [Carpenter et al., 1972]. The present note extends these comparisons, showing relations between the electric fields previously reported, auroral activity, and mid- and high-latitude magnetic perturbations. The case studies indicate that the 'growth phase' signature of the westward electric field observed within the plasmasphere may differ appreciably from the signature reported to exist at greater distances. This note also reveals a close temporal relation between a rapid, substorm-associated rise in the westward component of electric field in the plasmasphere, E_w , and a well-known type of nightside geomagnetic perturbation.

Sources of data. The data include records from magnetic observatories in the U.S., Canada, Iceland, and Antarctica, all-sky camera records from Byrd, Antarctica, and VLF convection electric field data from Eights, Antarctica. Figure 1 shows the distribution of stations in invariant latitude and magnetic local time at ~ 0600 UT, when Eights and Byrd are near local midnight. For illustration, the solar direction is taken as upward, and the SM Z-axis as out of the paper. A circle of radius 600 km represents the field of view of the Byrd all-sky camera. The dashed curve shows the approximate 'viewing' area of the Eights whistler station ($L \sim 4$). The east-west component of electric field at various equatorial points that map into this area was deter-

mined from observations of cross-L drifts of multiple whistler paths. (In the present application of the whistler method, information on path L value is obtained; path longitudinal position within the viewing area is not known. For further information on the method, see Carpenter et al., [1972]).

The mid-latitude magnetic observatories (open triangles in Figure 1) range westward from Agincourt (AG) and Fredericksburg (FR), near the meridians of Eights and Byrd, to Victoria, Canada (VI). The higher-latitude group (open circles) range from Leirvogur (LE), about 3 hours east of Eights, Antarctica to College, Alaska (CO), about 6 hours to the west. Byrd (all-sky camera) and Eights are separated by about one hour in magnetic local time.

II. CASE STUDY OF JULY 29, 1965

Figure 2 compares E_w variations on July 29, 1965 with variations of the interplanetary magnetic field and of the surface geomagnetic field. Figure 3 shows corresponding all-sky camera data. At the top in Figure 2 are the IMP-3 5.46-minute averages of B_{\perp} , the interplanetary magnetic-field component normal to the earth's dipole equator (solar magnetic coordinates). Next are E_w variations in the outer plasmasphere at $4 \lesssim L \lesssim 4.5$. (Interruptions and terminations of the E_w curves are due to corresponding changes in the measurable properties of observed whistlers). Next are H-component magnetic records from the higher-latitude stations shown in Figure 2. Below these are the H and D-component magnetic records from midlatitude stations on the North American continent.

The period of Figure 2 is centered roughly 36 hours following the beginning of a weak magnetic storm and during a period of regular but relatively well separated surges of substorm activity. Sums of K_p on the 26th, 27th, 28th and 29th were 7, 16, 23 and 20, respectively. Hourly D_{st} for

05-06 UT on July 29th was -6 gamma.

The relation of E_w and D. A prominent feature of Figure 2 is the approximate time coincidence of the large surge of westward electric field at $\sim 0520-0620$ UT and perturbations in nearly all the magnetic traces. One of the best defined magnetic effects is in the D-component variations (Figure 2, bottom). These began at about the time of the rapid increase in E_w at 0520-0530 UT and appear to be typical substorm-associated D events (see Akasofu and Meng [1969], Meng and Akasofu, [1969]). At Victoria the deflection in D was eastward. Tucson and Boulder appear to have been in a transition region, while at Dallas and further east the deflection was westward. The D events near the meridian of Eights (Fredericksburg and Agincourt) showed maximum westward deflection near the time of peak E fields, and decayed as E_w dropped to zero. The E field then reversed to be relatively large and eastward, but there was no similar change in D. The relation between E_w and the Fredericksburg D-component is shown on an expanded time scale in the middle and lower parts of Figure 4.

The relation of E_w and auroral activation. In the period of rapid increase in E_w at 0520-0530 UT, Byrd all-sky photographs (Figure 3, sixth row) showed an enhancement of auroral activity near the northeast horizon (upper right in the photographs), which is the equatorward boundary of the auroral oval near the midnight meridian. Auroral activity then spread rapidly toward the morning sky, a typical morning feature of an auroral substorm. The aurora were most active in the period 0540-0600 UT, when both the electric field and negative bay at Byrd were near their peak intensities.

The electric field reversed its sign to become eastward at ~ 0620 UT. This coincided approximately with a reversal of auroral motions. Between 0600 and 0617 UT aurora were drifting eastward. At about 0618 UT a bright

5

band appeared near the zenith of Byrd and moved rapidly westward (see the photographs taken at 0620 and 0625 UT). It is not clear how the reversal in cross-L plasmaspheric drifts from inward to outward is related to this auroral reversal from eastward to westward. There was no clear poleward or equatorward motion of auroras in the period immediately following 0650 UT.

The interplanetary magnetic field. The relation of the interplanetary magnetic field and E_w for this case was discussed briefly by Carpenter et al., [1972]. In Figure 2 (top) the comparison is changed slightly so as to present the interplanetary data in terms of B_{\perp} , the component normal to the earth's dipole equator. As noted in the previous paper, there appears to be a relationship between negative increases in B_{\perp} at \sim 0200, 0430, and 0650 UT and a sequence of bays shown, for example, by the Byrd magnetometer. The relationship is similar to the type recently discussed by Foster et al [1971], Nishida [1971], Arnoldy [1971], and Rostoker et al [1972], among others. The largest bay event, near 0530 UT, follows a negative increase in B_{\perp} of about 7 γ near 0430 UT. The negative excursion of the interplanetary field was relatively brief, decaying after about one hour as the more intense part of the E_w event developed.

Growth phase? The brevity of both the interplanetary event and the following substorm complicates identification of a 'growth' phase in the data. The increase in E_w near 0500-0510 UT occurred near the time of a slight increase in brightness of auroras (Figure 3, sixth row). At Leirvogur there was a beginning of a negative bay at 0455 UT (Figure 2), and abrupt beginnings occurred at Churchill and Byrd at 0520 and 0525 UT, respectively. At \sim 0525 UT, when nearby auroral and bay activation occurred, E_w had not already 'grown' to a relatively large, increasing level, but instead rose rapidly from low levels at this time.

6

The correlated nature of the rapid increase in E_w and other effects is emphasized in Figure 4. The Byrd ASC films, samples of which appear in the top panel, reveal that auroral activation occurred on the northeast horizon (in the general direction of Eights) at 0523 ± 1 min. An uncalibrated micro-pulsation record from Eights (2nd panel) shows the onset of a Pi2 event at $\sim 0522 \pm 20$ sec. In a recent review, Rostoker [1972] noted the value of Pi2 bursts as indicators of substorm onsets.

The onset times of the auroral activation and Pi burst fall well within the interval 0525 ± 5 min., which is our present estimate of the beginning of the rise in E_w near $L = 4$ (3rd panel). Improved resolution of the E_w variations is expected as the whistler technique is further developed.

III. CASE STUDY OF AUGUST 20, 1965

Figure 5 repeats for August 20, 1965 the format used in Figure 2, and Figure 6 presents examples of corresponding Byrd all-sky camera films. As in the July-29 case, a weak magnetic storm was underway, but the August event was preceded by activity of somewhat greater intensity and longer duration. Sums of K_p on August 17, 18, 19 and 20 were 19, 19, 30 and 24 respectively. Minimum hourly D_{st} during the interval of Figure 5 was -10γ at 10-11 UT.

Activity on August 20, 1965 was previously described by Coroniti et al [1968], who noted the occurrence of several large substorms in close succession between ~ 07 and 13 UT. The prolonged nature of the activity is reflected in the E_w curves of Figure 5, which do not exhibit a reversal after the large westward increase, but instead remain westward until near local dawn (~ 11 UT).

Relation of E_w and D. As in Figure 2, there is a correlated event in the E_w curves and many of the magnetic signatures. The D variations resemble those of Figure 2 in several respects, exhibiting a large deflection at ~ 0730 UT when the westward field began its main substorm increase. The August 20 D

7

event appears to recover slowly in comparison to the 'isolated' event of July 29, probably reflecting the prolonged nature of the associated substorm activity.

Relations of E_w , auroras, IMF B_\perp and bay activity. The interplanetary magnetic field component normal to the dipole equator began a brief negative excursion near 0410 UT, reaching a maximum negative value of $\sim -4\gamma$ at ~ 0455 UT, and then quickly reversing to positive values at ~ 0505 UT. Shortly after 0500 UT there was a small bay event at Byrd, accompanied by a westward surge (see the all-sky photographs at 0510-0515 in Figure 6). No clearly related changes in E_w were detected in the observed whistler paths at $L \sim 3.7$.

Near 0550 UT, B_\perp turned sharply downward and began an initially irregular but enduring negative trend. At ~ 0620 UT, E_w in the outer plasma-sphere ($L \sim 3.7$) turned positive and began to fluctuate near ~ 0.15 mV/m. Examination of the Byrd all-sky photographs revealed an enhancement of the brightness of auroras near the equatorward horizon at 0638 UT. The auroras were active, but too distant for detailed examination of motions. At Flin Flon (position FF in Figure 1), an impulsive precipitation event (balloon x-rays) was observed at 0640 UT (Coroniti et al [1968]).

At ~ 0730 there was an increase in E_w as a negative bay began at Byrd. Coroniti et al [1968] reported a large impulsive electron precipitation event at Flin Flon at 0735, and concluded from Flin Flon and College magnetograms that a substorm expansion phase began at this time. At about 0750 UT there was a further increase in E_w as auroras observed from Byrd (Figure 6) began to spread poleward, first rather slowly and at 0755 UT more rapidly. Active displays continued until twilight (~ 1400 UT).

IV. CONCLUDING REMARKS

In two substorm studies, a large (factor of ~ 5) surging increase in westward electric fields in the outer plasmasphere at $L \sim 4$ was found to be closely correlated in time with an enhancement of auroral activity observed from Byrd, Antarctica ($L \sim 7$). The auroral and E_w observations were coincident in longitude within about 15 degrees. Prior to the large E_w increase and auroral activation, there was activity in E_w at lower levels near 0.1-0.2 mV/m. This activity appeared to be correlated with one or more of the following: distant auroral activity, small local fluctuations in auroras, x-ray precipitation events, and minor magnetic disturbances. It is not yet clear in what sense this initial activity in E_w may be classified as a 'growth phase' effect.

The foregoing description of E_w variations differs from the electric-field signatures found from balloon-borne detectors by Mozer [1971], who reported a growing westward field that reaches a high level prior to the time of auroral activation. The lack of agreement may be due in part to the great variety and complexity of substorms, and to the attendant difficulties in identifying (and obtaining agreement upon) the various stages of substorm development. The differences may also be real, reflecting a shielding effect such as that recently discussed by Karlson [1971] and by Vasyliunas [1971], among others. These authors describe, from various points of view, the process by which motions of energetic particles in the outer magnetosphere give rise to particle pressure gradients and to charge-separation electric fields. The latter in turn cause the intensity of the convection electric field to be reduced at points interior to the regions of the pressure gradients. Note that the whistler and balloon methods tend to emphasize different regions,

the whistler method being most readily applied in the plasmasphere near $L = 4$, while the balloon technique favors those slightly higher- L regions where the mapping factors relating magnetospheric and ionospheric electric fields become large.

Recent comparisons of data from whistlers and balloons by one of the authors (DLC) and by F. Mozer (personal communication) show several examples of agreement on the sign of E_w during relatively quiet conditions. Future experiments with suitable overlap in time, magnetic conditions and L space will hopefully clarify present differences on substorm effects.

The second main point of interest in the two case studies is the occurrence at middle latitudes of a large deviation of the D component of the geomagnetic field at about the onset time of the main surge of westward electric field (similar events have been observed in case studies on July 15, July 25, and October 13, 1965, and June 29, 1967). The deviation was westward in the longitude range of the convection electric field observations. At present it is not clear how the E_w increase and the D event are related. In dipole geometry, a westward electric field in the magnetosphere of 0.5 mV/m at $L = 4$ will map to the ionosphere with an intensity of 4 mV/m (see Mozer [1970]). If the Hall conductivity is sufficiently high, this field might cause an appreciable westward deflection of the geomagnetic field. However, the D component does not exhibit a pronounced reversal at the time of the reversal in E_w in the magnetosphere. Furthermore, large substorm-associated increases in E_w within the plasmasphere are frequently localized in longitude, and in particular do not usually extend well into the pre-midnight sector (e.g. Park and Carpenter [1969]). In contrast, the D (and H) events are evidently spread widely in longitude (Figures 2 and 5), and may reflect a large scale pattern of field-aligned currents. Indeed, the longitudinal variations of the D

16

component (from Victoria to Agincourt) are in good agreement with the pattern discussed by Akasofu and Meng [1969], and Meng and Akasofu [1969]. We tentatively conclude that E_w within the plasmasphere surged rapidly when the field-aligned current system began to grow. Improved knowledge of these relationships should result from expected future improvements in resolution of the onset time of E-field events.

ACKNOWLEDGEMENTS

We are grateful to C. Meng for helpful discussions and for providing the IMP-3 interplanetary magnetic field values in solar magnetic coordinates. The work at Stanford(DLC) was supported in part by the National Science Foundation under Grants GA-32590X and GA-18128, in part by the Office of Polar Programs under Grants GV-28840X and GA-12317, and in part by the National Aeronautics and Space Administration under grant NGL-05-020-008. Computer facilities were sponsored in part by the Office of Computer Sciences of the National Science Foundation under Grant NSF GP-948.

The research at the Geophysical Institute (S-I A) was partly supported by the National Science Foundation under Grant GA-28101.

-12

BIBLIOGRAPHY

- Akasofu, S.-I. and C.-I. Meng, A study of polar magnetic substorms, J. Geophys. Res., 74, 293, 1969.
- Arnoldy, R. L., Signature in the interplanetary medium for substorms, J. Geophys. Res., 76, 5129, 1971.
- Cauffman, David P. and Donald A. Gurnett, Double-probe measurements of convection electric fields with the Injun-5 satellite, J. Geophys. Res., 76, 6014, 1971.
- Carpenter, D. L. and Keppler Stone, Jan C. Siren and T. L. Crystal, Magnetospheric electric fields deduced from drifting whistler paths, J. Geophys. Res., 77, June, 1972.
- Foster, J. C., D. H. Fairfield, K. W. Ogilvie, and T. J. Rosenberg, Relationship of interplanetary parameters and occurrence of magnetospheric substorms. J. Geophys. Res., 76, 6971, 1971.
- Haerendel, G., Plasma drifts in the auroral ionosphere derived from barium releases, to be published in Earth's Magnetospheric Processes, B. McComac (ed), D. Reidel Co., Dordrecht, Holland, 1972.
- Heppner, J. P., Electric field variations during substorms: OGO-6 measurements, presented at the Symposium on Morphology and Physics of Magnetospheric Substorms, XV IUGG General Assembly, Moscow, 1971. To be published in Planet.Space Sci., 1972.
- Karlson, Erik T., Plasma flow in the magnetosphere; 1. A two-dimensional model of stationary flow, Cosmic Electrodynamics, 1, 474, 1971.
- Maynard, N. C., Electric fields in the ionosphere and magnetosphere, Paper presented at the Advanced Study Institute on Magnetosphere-Ionosphere Interaction, Dalseter, Norway, April 14-23, 1971.
- Meng, C.-I. and S.-I. Akasofu, A study of polar magnetic substorms, 2. Three-dimensional current system, J. Geophys. Res., 74, 4035, 1969.
- Mozer, F. S., Electric field mapping in the ionosphere at the equatorial plane, Planet.Space Sci., 18, 259, 1970.
- Mozer, F. S., The origin and effects of electric fields during isolated magnetospheric substorms, J. Geophys. Res., 76, 7595, 1971.
- Nishida, A., Interplanetary origin of electric fields in the magnetosphere, Cosmic Electrodynamics, 2, 350, 1971.
- Park, C. G. and D. L. Carpenter, Whistler evidence of large-scale electron-density irregularities in the plasmasphere, J. Geophys. Res., 75, 3825, 1970.
- Rostoker, Gordon, Polar magnetic substorms, Rev. Geophys. & Space Phys., 10, 157, 1972.
- Rostoker, Gordon, Hing-Lan Lam, and William D. Hune, Response time of the magnetosphere to the interplanetary electric field, Canadian Journal of Physics, 50(6), 1972.

ILLUSTRATIONS

Figure 1. Distribution in invariant latitude and magnetic local time of ground stations providing data used in the present report. The distribution is illustrated for ~ 06 UT, when the two southern-hemisphere stations Eights (EI) and Byrd (BY), Antarctica are near local midnight. A circle of radius 600 km centered at Byrd represents the field of view of the Byrd all-sky camera. Open circles represent the high-latitude magnetic observatories Leirvogur (LE), Churchill (CH), Baker Lake (BL), Meanook (ME) and College (CO). Open triangles represent the midlatitude magnetic observatories Fredericksburg (FR), Agincourt (AG), Dallas (DA), Boulder (BO), Tucson (TU), and Victoria (VI).

Figure 2. Comparison of the westward electric field in the magnetosphere and various magnetic records during a July 29, 1965 period of substorm activity. The top panel shows IMP-3 data on the interplanetary magnetic field component perpendicular to the dipole equator (transformation from solar ecliptic coordinates courtesy of C. Meng). The second panel shows details of the westward component of the magnetospheric equatorial electric field near $L = 4$, determined from whistlers observed at Eights, Antarctica. The third panel shows high latitude H-component magnetic traces from the observatories identified in Figure 1. The bottom panel shows the H and D-component signatures from the middle-latitude observatories identified in Figure 1.

Figure 3. Selected Byrd, Antarctica all-sky camera photographs from the July 29, 1965 period illustrated in Figure 2. Magnetic north (equatorward) is to the upper right in the photographs; magnetic west is to the upper left.

Figure 4. Expanded time-scale presentation of the correlated event of July 29, 1965. The third panel shows the electric field signature presented on the second panel of Figure 2. At the top is a set of Byrd, Antarctica all-sky photos from Figure 3, repeated for detailed comparison with the micropulsation record from Eights, Antarctica in the second panel. The H and D components from the Fredericksburg magnetometer, near the meridian of the whistler observations, are shown in the lower part of the figure.

Figure 5. Comparison of the westward electric field in the magnetosphere and various magnetic records during an August 20, 1965 period of substorm activity. The format is essentially the one used in Figure 2.

Figure 6. Selected Byrd, Antarctica all-sky camera photographs representing the August 20, 1965 period of Figure 5. Magnetic north (equatorward) is to the upper right of the photographs; magnetic west to the upper left.

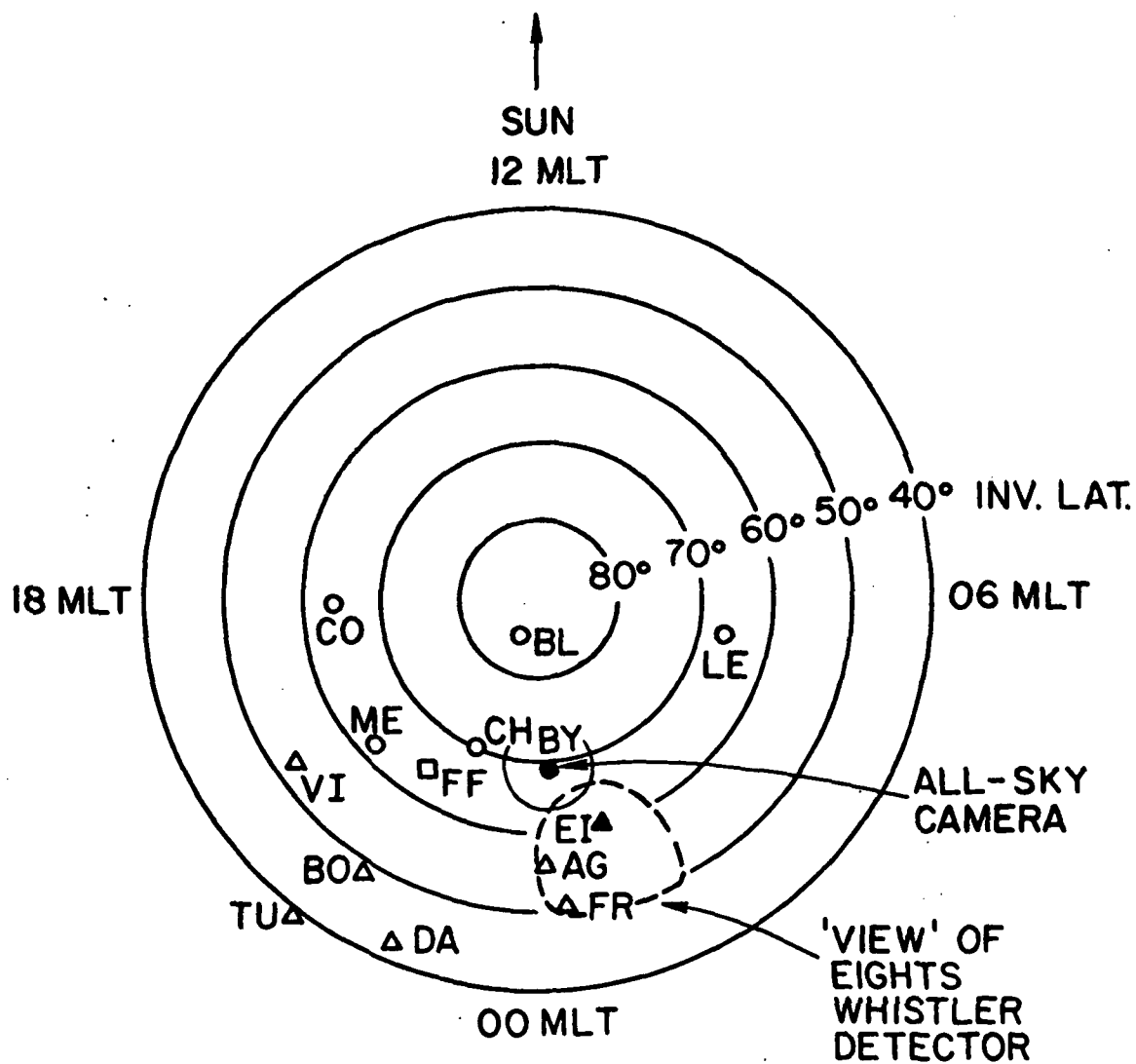


FIGURE 1.

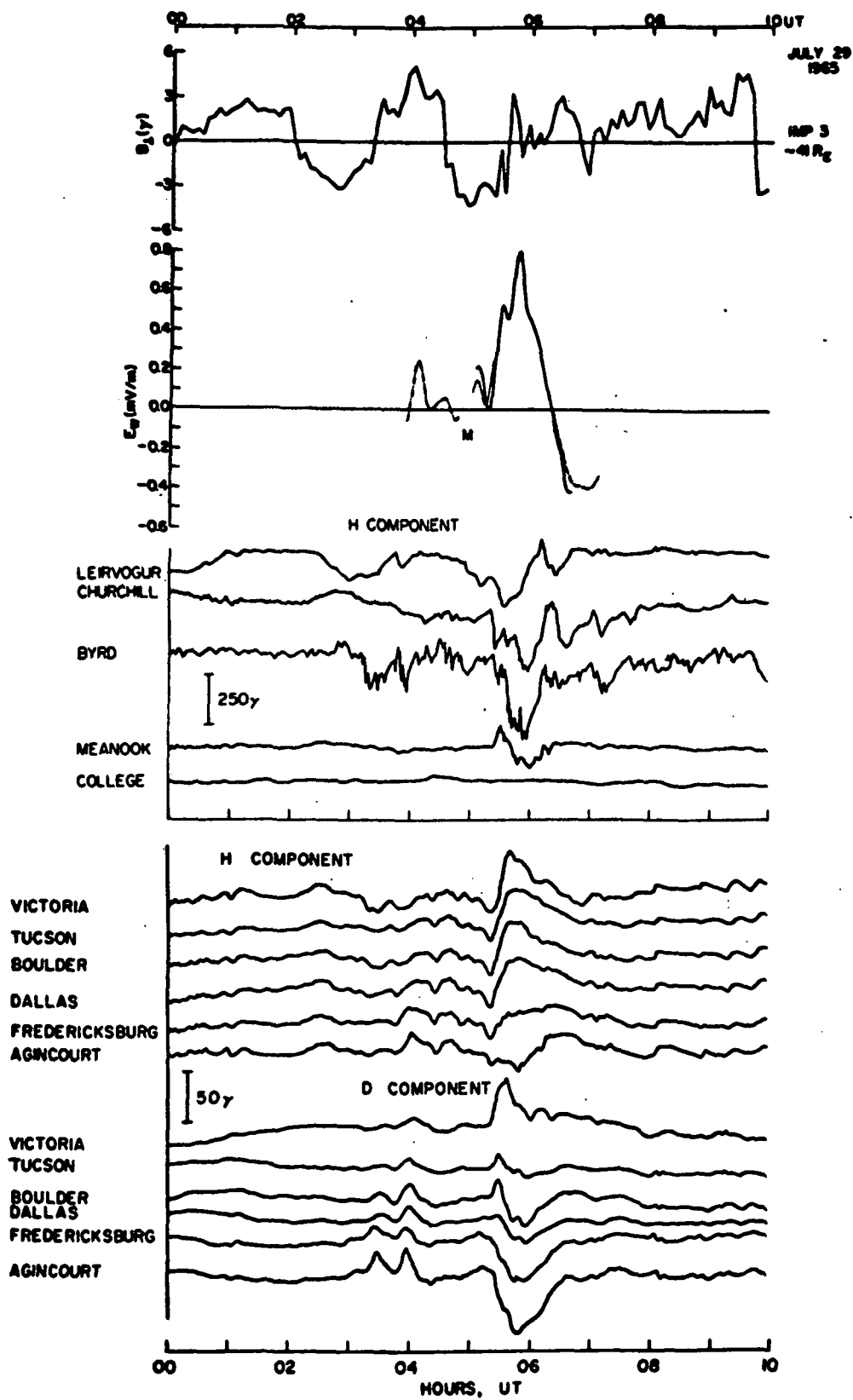


FIGURE 2.

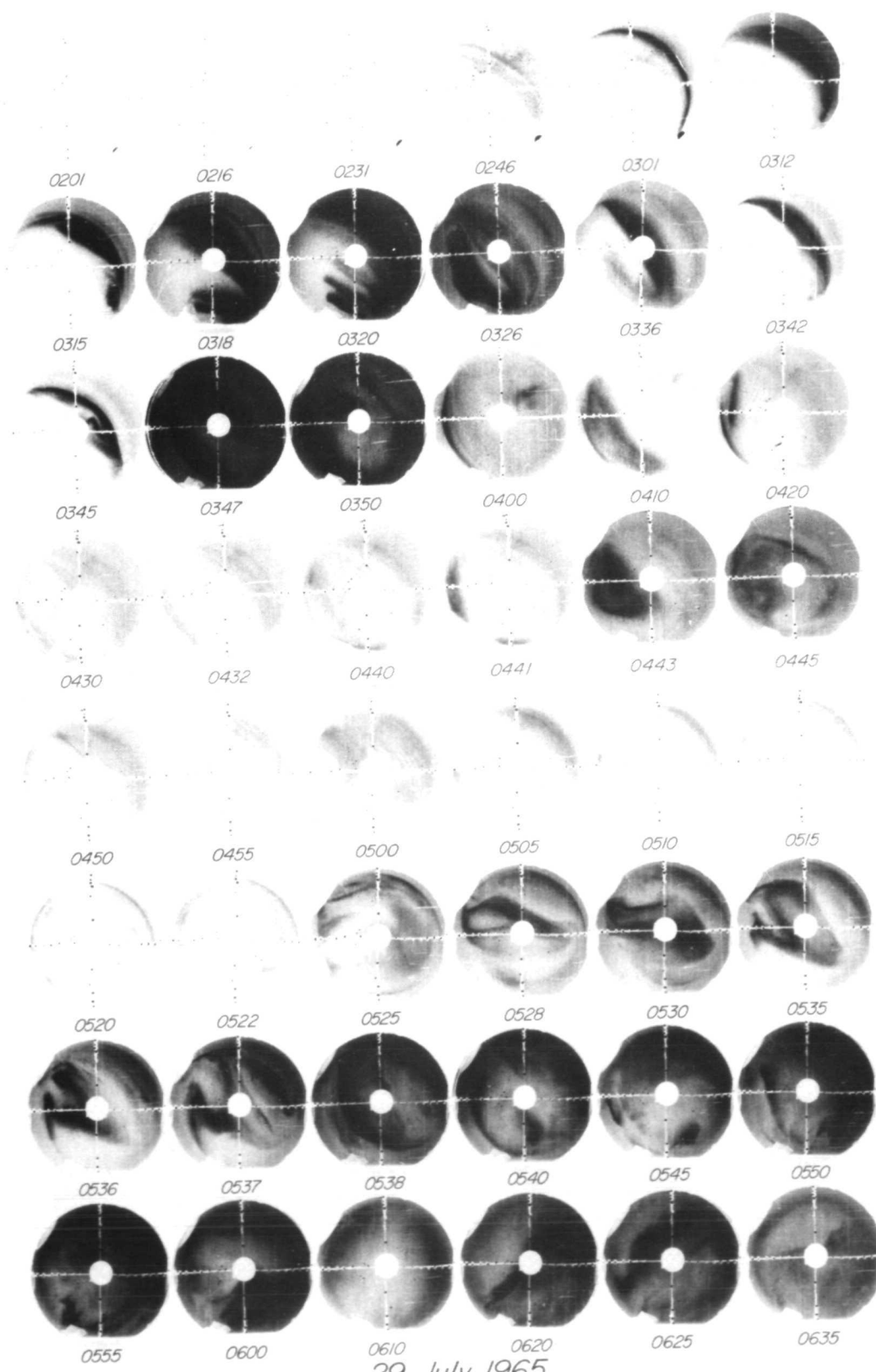


Figure 3.

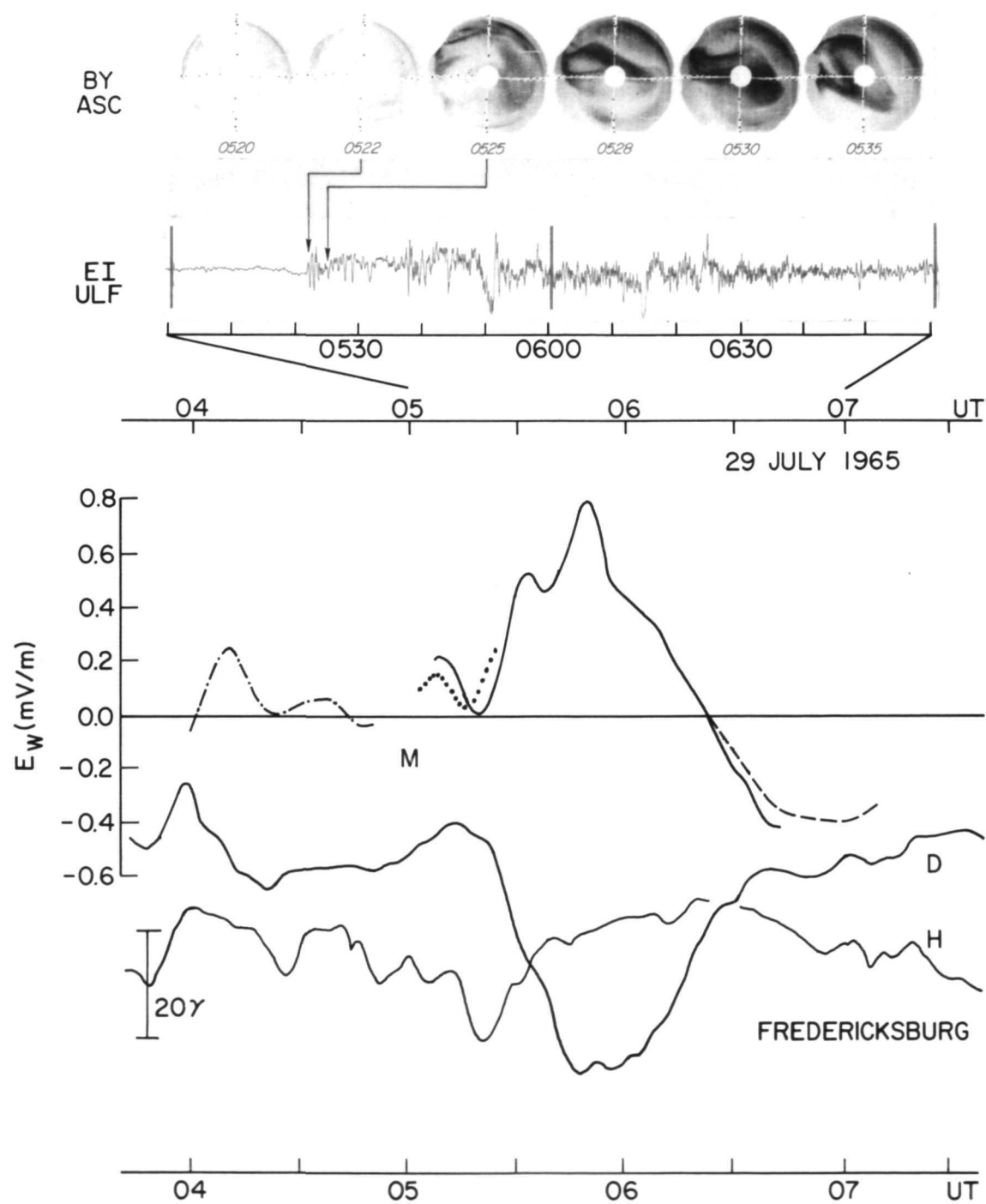


Figure 4.

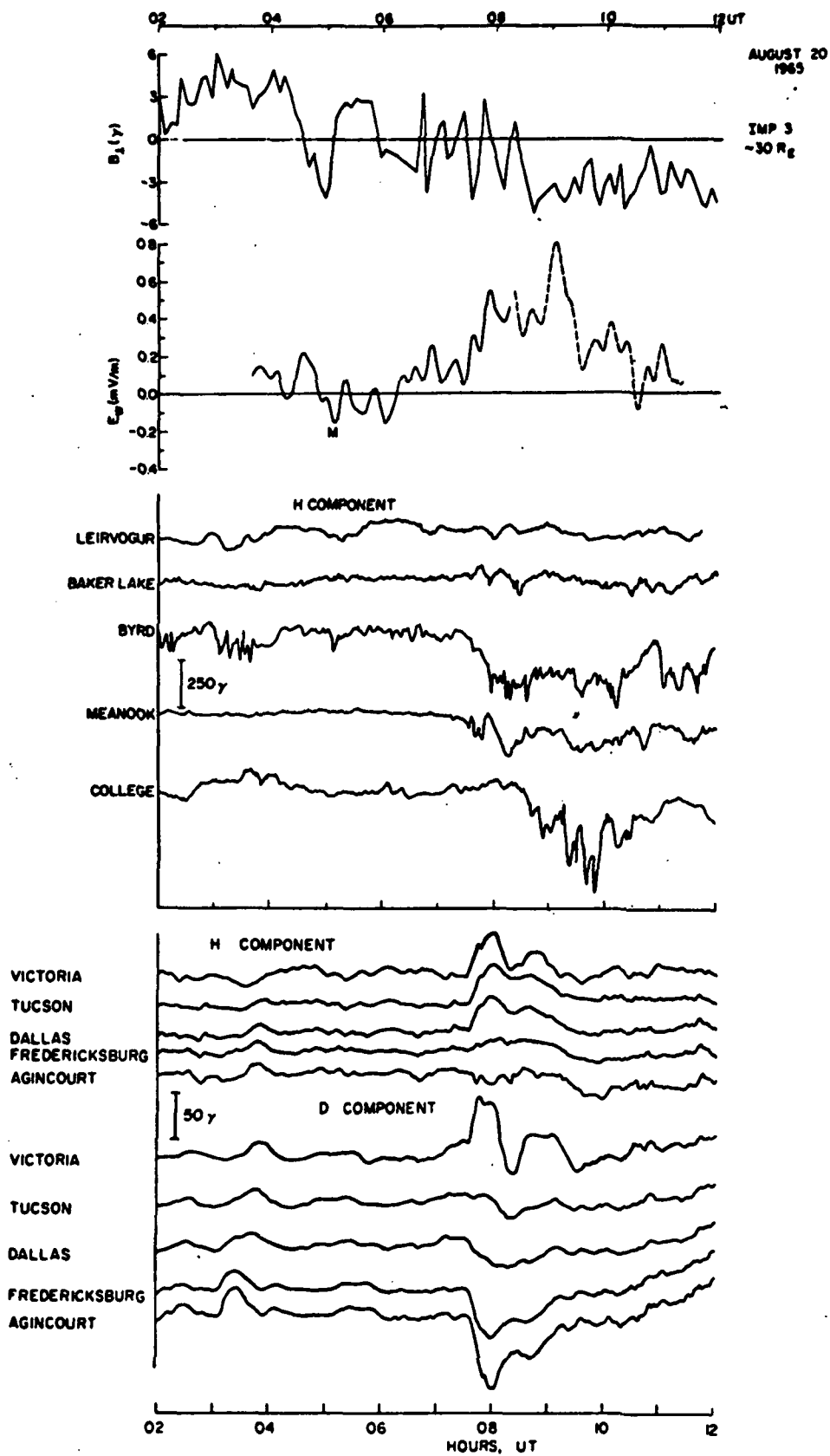


FIGURE 5.

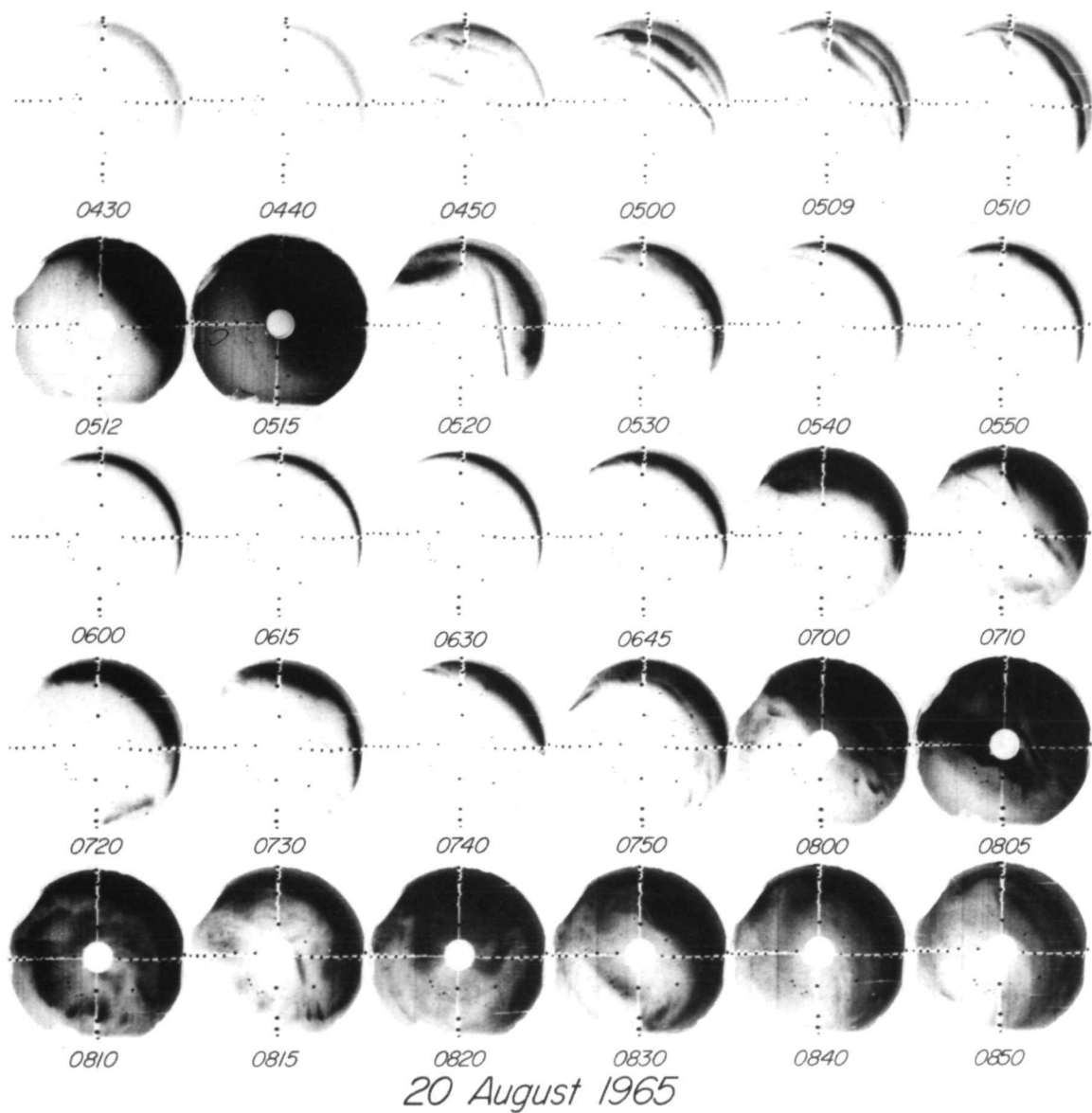


Figure 6.