X-612-69-411
PREPRINT

NASA TM X- 63679

AURORAL AND POLAR CAP ELECTRIC FIELDS FROM BARIUM RELEASES

EUGENE M. WESCOTT
JOHN D. STOLARIK
JAMES P. HEPPNER

AUGUST 1969

NASA — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

AURORAL AND POLAR CAP ELECTRIC FIELDS FROM BARIUM RELEASES

Eugene M. Wescott[1], John D. Stolarik and James P. Heppner

August 1969

Presented at the Summer Advanced Study Institute, "Earth's Particles and Fields, 1969", Santa Barbara, California, August 4-15, 1969.

1. NAS Resident Research Associate, NASA Goddard Space Flight Center, now at Geophysical Institute, University of Alaska.

INTRODUCTION

High latitude magnetic disturbances and accompanying auroral displays are obvious evidence of the release of large amounts of energy, presumably from the magnetosphere and magnetotail regions. Until recently experimental efforts towards understanding these phenomena were directed toward measurements of magnetic fields, energetic particles, optical emissions and the morphology of the observables. The importance of ionospheric and magnetospheric electric fields was recognized in theoretical studies, but actual measurements were not available due to the lack of suitable techniques. In the past several years valid electric field measurements have been made from sounding rockets and satellites with long antennas (AGGSON, 1969; MAYNARD and HEPPNER, 1970). Another method, more suited for making $\underset{\sim}{E}$ field observations simultaneously at several points and for extended times at a given location was developed at the Max Planck Institut (FÖPPL et al., 1967). Barium vapor released from a sounding rocket above about 150 km partially ionizes and produces during twilight a visible ion cloud which can be tracked photographically. The ion cloud drifts under the influence of the electric and magnetic fields, and it can be shown that the velocity of a small cloud above 200 km altitude is given essentially by $\underset{\sim}{v} = \underset{\sim}{E} \times \underset{\sim}{B}/B^2$. Inverting this equation to $\underset{\sim}{E} = -\underset{\sim}{v} \times \underset{\sim}{B}$, the measurement of $\underset{\sim}{v}$ in a known magnetic field $\underset{\sim}{B}$ gives $\underset{\sim}{E}$.

The GSFC-NASA barium release experiments have produced high latitude observations of 23 ion clouds in the auroral zone and 12 in the polar cap region. From these observations we can draw conclusions about the nature of the ionospheric electric fields and the tensor conductivity elements that are most effective in producing ionospheric currents. The measurements also test the usual assumption that the surface magnetic disturbance is explained by ionospheric currents. From ground based magnetometers a typical equivalent ionospheric current pattern for the polar cap and auroral zone disturbance can be inferred. Figure 1 shows a diagram illustrating the essential features. Our E field investigations have sampled four regions of interest: 1) in the westward electrojet or negative magnetic bay region, 2) in the eastward electrojet region, 3) in the transition region where the westward electrojet passes polewards of the eastward jet and 4) in the polar cap region. Visible auroral displays were observed in the barium release region, or close by, in all flights except those in the polar cap where auroras were seen only near the southern horizon.

WESTWARD ELECTROJET REGION

On the evenings of August 31 and September 2, 1967 rocket flights from Andøya, Norway released 8 barium clouds in or slightly north of the westward electrojet (WESCOTT et al., 1969). The ion cloud speeds differed on the two occasions, but the direction of motion with respect to the magnetic disturbance vector was the same. The August 31, 1967 flight illustrates the salient features of the electric field in the westward electrojet region with auroral forms present. At the time of the barium releases the nearby ground magnetograms at Andøya and Trømso, Norway and Kiruna, Sweden showed a negative bay in H of -150γ which continued during the observation period to -340γ. Typical post breakup auroral arcs of varying brightness and activity existed in the release region during the observation and a quiet faint arc remained nearly stationary about 100 km to the south.

Figure 2 illustrates the ion cloud positions, projected down the magnetic field lines to 100 km altitude vs. time. All motions were eastward with speeds most typically between 700 and 1000 m/s. The corresponding electric fields were 35-50 mv/m directed southward, perpendicular to the velocity. Figure 3 shows the velocity vectors and the positions of the auroral arcs at four times during the observations. The ion clouds were observed to move closely parallel to the arc alignments. A comparison of the electric field direction with the magnetic perturbation vector revealed agreement within 5^{o}. This implies that the current was nearly perpendicular to the $\underset{\sim}{E}$ field in the Hall current direction.

All results of the September 2 flight agreed with those of August 31 except that higher $\underset{\sim}{E}$ fields $\approx$ 130 mv/m during a smaller negative bay were observed. This fact illustrates that the ionospheric conductivity varies considerably and that one cannot predict the magnitude of $\underset{\sim}{E}$ solely from the ground magnetograms. The surface disturbance does, however, appear to be reliable in determining the direction of $\underset{\sim}{E}$ as would be expected for Hall currents.

TRANSITION AND EASTWARD ELECTROJET REGION

Two flights, on 12 September 1967 and 20 September 1968 from Andøya, Norway were planned to measure the electric field in the region of the eastward electrojet. The launch conditions were auroral activity in the release area and a positive magnetic bay in H at the nearest magnetic stations, Andøya and Tromsø. In each case three useful barium clouds were formed, the most southernly two obviously were in the eastward current region. On 12 September 1967 the northern most cloud, however, apparently spanned the transition region and temporarily moved eastward in accordance with the electric field of the westward electrojet before moving westward at the time of an enhancement in the positive bay disturbance. This flight has been discussed previously (WESTCOTT et al., 1969).

The results of the flight of 20 September, 1968 are more complex to understand, but are more interesting because of more complete auroral information. During the observation interval the magnetogram shows a ΔH of about + 30γ and a west component of 20γ. The 100 km projected ion cloud positions vs time are shown in Figure 4. Both clouds 1 and 2 became elongated E-W while moving generally west or southwest. This motion is in reasonable agreement with the magnetic perturbation at Andøya (A on the map) if the current is predominantly Hall current. The most striking feature of the tracks in Figure 4 is the motion of the third cloud which is to the SE.

At launch a fairly active auroral arc was nearly overhead at Andøya, the launch site. After the barium releases the arc moved polewards and passed first through the projected position of cloud 1 and then of cloud 2 and eventually remained in the cloud 3 position for most of the observation period. The ion cloud motion did not correspond to the poleward motion of the arc, which implies that the cause of the poleward auroral motion was not directly associated with an outward plasma motion in the magnetosphere.

The ion cloud velocity was low at the time the barium clouds and auroras were in the same shell. Figure 5 illustrates the calculated $\underset{\sim}{E}$ field magnitude vs time for the three clouds. At the times of auroral crossings the $\underset{\sim}{E}$ field dropped to less than 10 mv/m. This is particularly evident in the cloud 2 data where the contact extended over three minutes. These observations confirm probe measurements which showed a low $\underset{\sim}{E}$ field inside auroral forms (AGGSON, 1969).

CONCLUSIONS ON ELECTROJET REGION

1. The E field direction is consistent with observed magnetic perturbations for an ionospheric current which is predominantly Hall current.
2. $|E|$ ranges from less than 10 mv/m to greater than 100 mv/m.
3. Observations show that $|E|$ is low inside auroral forms, which argues against having a polarization field drive Cowling currents to explain the electrojets.
4. Assuming that magnetospheric convection is closely related to the ion drifts observed, the auroral substorm convection is primarily E-W or W-E with dominant inward motions confined to the auroral break-up region where E reverses.
5. $|E|$ cannot be simply related to the magnitude of ΔB, hence the conductivity distribution is needed to predict $|E|$ from $|\Delta B|$.
6. The polewards motion of an auroral arc does not imply any direct connection with the E field, or outward plasma drift in the magnetosphere. Explanation in terms of a change in the energy of precipitation particles appears more promising.
7. The strong northward and southward directed E fields, respectively, in the eastward and westward electrojet regions and the behavior of Ba^+ clouds in the transition between the two electrojets is in excellent agreement with the two cell configuration (Figure 1) and contrary to treatments of the eastward electrojet as a mere return current from the westward electrojet.
8. E is not uniform in space or time and there can be large shears over a short distance.

9. The velocity of the auroral zone ionosphere is often supersonic with respect to the neutral atmosphere.
10. Striations aligned along $\underset{\sim}{B}$ are a common feature of the auroral zone Ba^+ clouds. Their existence, growth, and size does not appear to be related to altitude above 200 km or the time after release. Some form of $\underset{\sim}{E} \times \underset{\sim}{B}$ instability is suggested.
11. Abnormal vertical motions of the Ba^+ clouds that might suggest a strong $\underset{\sim}{E}$ field parallel to $\underset{\sim}{B}$ have not been observed.

POLAR CAP ELECTRIC FIELDS

Referring to Figure 1, the essential characteristic of magnetic disturbance in the polar cap region is the wide spread uniform perturbation, such that the equivalent current lines run parallel across the cap. To determine the $\underset{\sim}{E}$ field in the polar cap 3 rocket flights, releasing a total of 12 barium ion clouds were conducted in March, 1969 from Cape Parry, N.W.T. (74.7°INL). The flight of 8 March 1969, an evening shot, has been analysed. The magnetic perturbation vectors in the polar cap and auroral oval (Figure 6) indicate that a classic type polar substorm, Figure 1, was in progress. The polar cap vectors from Mould Bay, Resolute Bay, and Alert show a very uniform 50-70γ disturbance. The vectors at Cape Parry and Cape Young (immediately to the south of the 4 tracks) are parallel to those at the higher latitude stations but have a slightly greater magnitude. Vectors at Pt. Barrow and College, Alaska, approximately 10° to the southwest, show a $+\Delta H$ disturbance that is in good agreement with the location of an auroral arc which was visible on the south horizon from Cape Parry and Cape Young. Figure 7 shows the tracks of the four clouds. All motions were nearly parallel over a wide area and the velocity was also reasonably smooth. The corresponding $\underset{\sim}{E}$ field was 30 to 40 mv/m. The remarkable result however is that the direction of $\underset{\sim}{E}$ is such that only a component of the magnetic perturbation could be caused by an overhead Hall current. The disagreement between the normal to the cloud motion and the disturbance vector would be even greater if a Pedersen current was present. If the overhead current was all Hall current the disagreement is between $55\text{-}65^{\circ}$.

This serious disagreement clearly shows that an appreciable component of the polar cap disturbance is not, due to horizontal ionospheric current. The non-ionospheric disturbance component remains to be explained. Aside from the ever popular field aligned currents we can suggest another possible mechanism, namely that in addition to the Hall current produced perturbation there is a perturbation vector directed towards the sun arising from the combination of solar wind compression of the magnetosphere, the tension on the magnetic field lines extending into the distant tail, and the nightside inflation of the near magnetosphere. These factors all produce a sunward directed vector in the polar cap and a self-consistent model is needed to see how large a sunward vector can be produced from these distant effects. Roughly 50 gammas is needed under the Kp=3 conditions of this example. It is also believed that the study of variations in the sunward component of the polar cap disturbance as a function of magnetospheric parameters simultaneously measured by satellites will provide important tests.

POLAR CAP CONCLUSIONS

1. $\underset{\sim}{E}$ appeared to be uniform over a large area and averaged 30-40 mv/m.
2. The direction of $\underset{\sim}{E}$ is such that only a component of the magnetic disturbance could be caused by Hall currents.
3. Pedersen currents cannot provide an explanation for the magnetic disturbance and inclusion of a Pedersen current component would only increase the discrepancy between the observed disturbance and a Hall current component.
4. The results imply a non-ionospheric component at lease comparable in magnitude to the magnitude of a Hall current component.

FIGURE CAPTIONS

Figure 1. Idealized equivalent current pattern for the auroral and polar cap substorm as viewed from above the N magnetic pole in magnetic latitudes and magnetic time.

Figure 2. Tracks of four ionized barium clouds, Aug. 31, 1967, projected along magnetic field lines to 100 km altitudes on geographic coordinates. Numbers along the tracks are minutes and seconds of 22nd hour UT. Dashed grid lines are INL and arrows indicate average neutral cloud velocities in m/s.

Figure 3. Time sequence of typical auroral situations and barium ion cloud locations and velocities, (m/s), flight of Aug. 31, 1967. All cloud positions projected down field lines to 100 km. $\underset{\sim}{E}$ is 90° clockwise of $\underset{\sim}{v}$ and $\approx v/20$ (mv/m).

Figure 4. Tracks of three ionized barium clouds Sept. 20, 1968, projected to 100 km altitude down magnetic field lines, plotted on geographic coordinates. Numbers along the tracks are minutes and seconds of 19th hour UT. Dashed grid lines are INL. Clouds 1 and 2 became elongated E-W, the triangulated end and middle points are shown. Note the velocity shear between clouds 3 (SE) and 1, 2 (WSW).

Figure 5. Magnitude of $\underset{\sim}{E}$ vs time for three clouds released on 20 Sept. 1968. Note the variability of $\underset{\sim}{E}$ in time and position. The low $\underset{\sim}{E}$ is apparent at times when the visible auroral arc is on ths same magnetic field lines as the various clouds.

Figure 6. North polar plot in magnetic latitude and magnetic time of the horizontal magnetic disturbance vectors at the time of release of the fcurth barium cloud, 03:25 UT, March 8, 1969. Numbers with each vector give the vertical component of the magnetic disturbance. Ba^+ cloud tracks projected to 100 km altitude are also shown.

Figure 7. Tracks (projected to 100 km altitude) for Mar. 8, 1969, plotted on geographic coordinates (solid lines) with INL (lines dashed).

REFERENCES

AGGSON, T. L.: 1969, Atmospheric Emissions, (Ed. by B. M. McCormac and A. Omholt), Van Nostrand Reinhold Co. N. Y., 305

FÖPPL, H., HAERENDEL, G., LOIDL, J., LÜST, R., MELZNER, F., MEYER, B., NEUSS, H., and RIEGER, E.: 1967, Planet. Space Sci. 15 (2), 357.

MAYNARD, N. C. and HEPPNER, J. P., 1970, this volume.

WESCOTT, E. M., STOLARIK, J. D., and HEPPNER, J. P.: 1969, J. Geophys. Res. 74 (14), 3469.

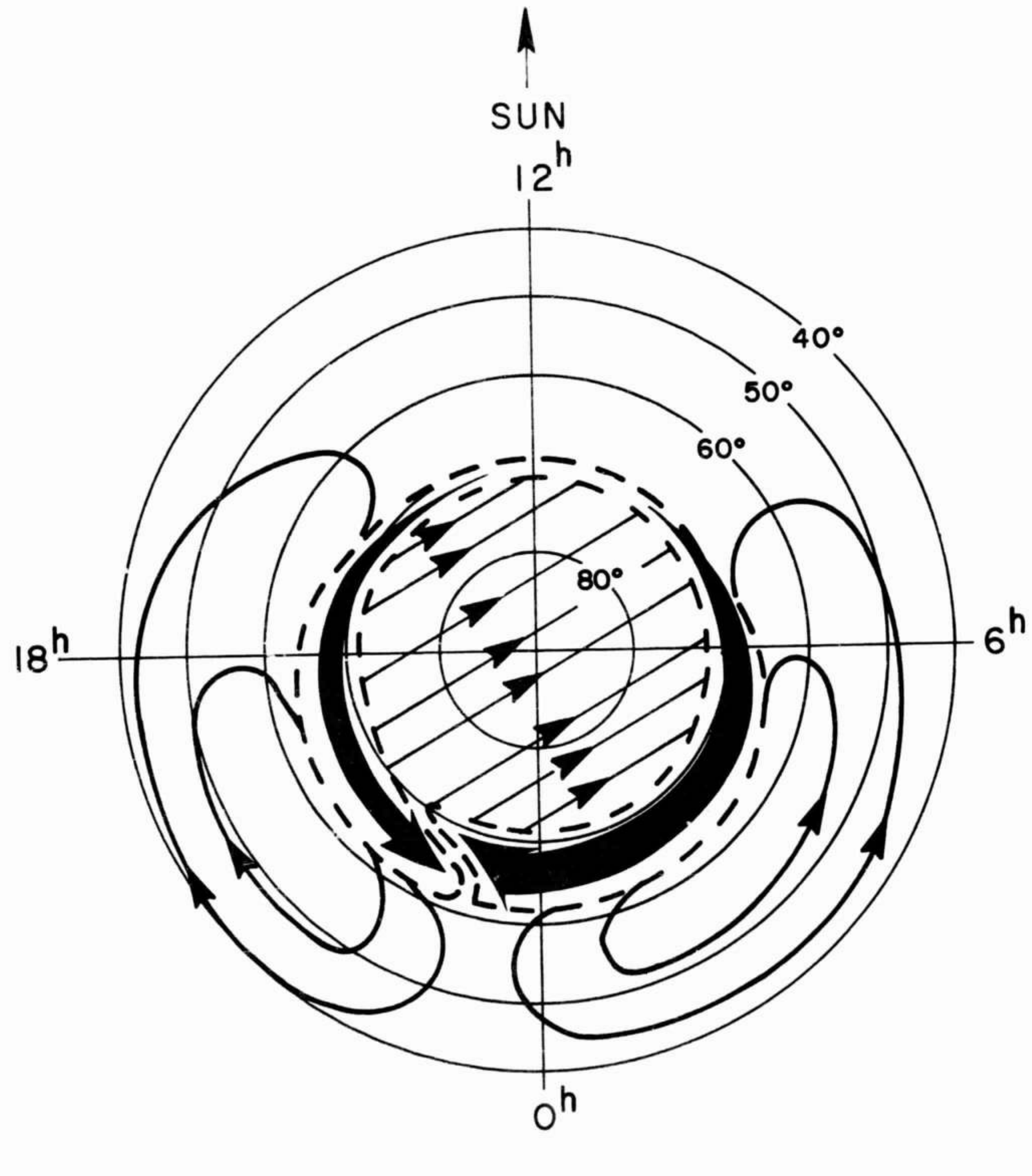


FIGURE 1

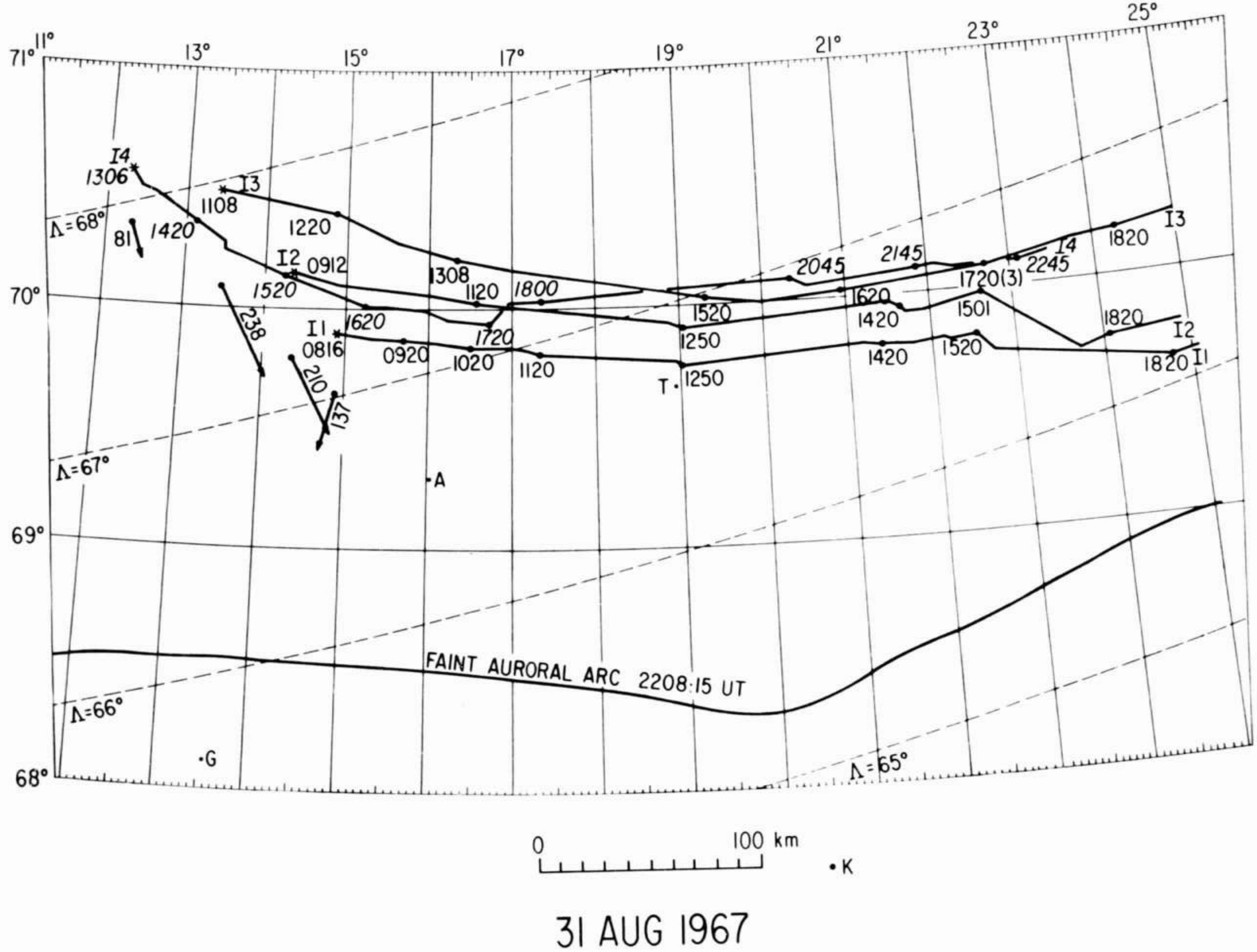

71°
11°
13°
15°
17°
19°
21°
23°
25°
70°
69°
68°
Λ=68°
Λ=67°
Λ=66°
Λ=65°
I4
1306
I3
1108
1220
1420
81
I2
0912
1520
238
1308
1120
1800
I1
0816
1620
1720
0920
1020
1120
210
137
A
G
T
1250
1250
1520
2045
2145
1620
1420
1720(3)
I4
2245
1501
1820
I3
1820
I2
1420
1520
1820
I1
FAINT AURORAL ARC 2208:15 UT
0
100 km
K
31 AUG 1967

FIGURE 2

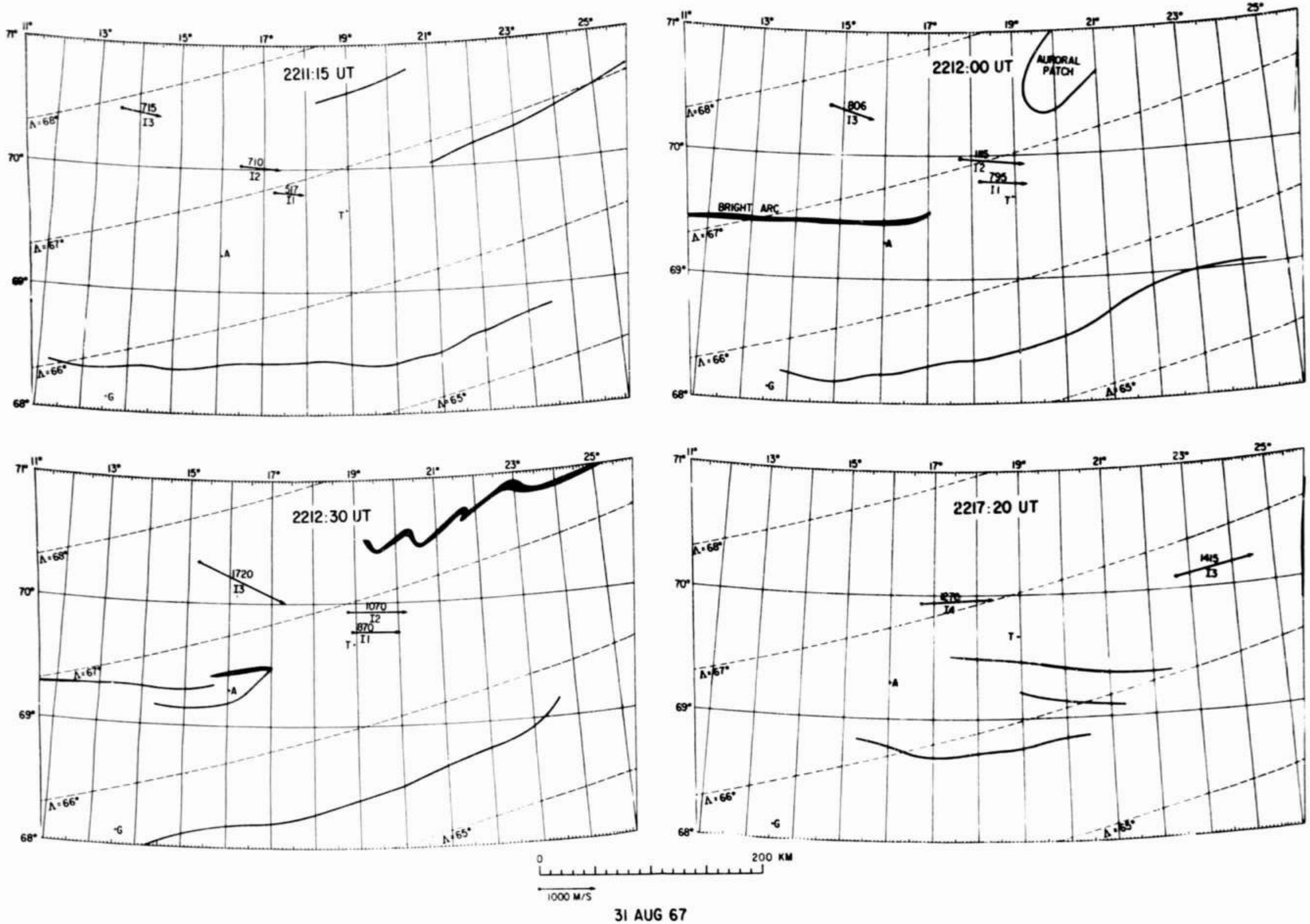
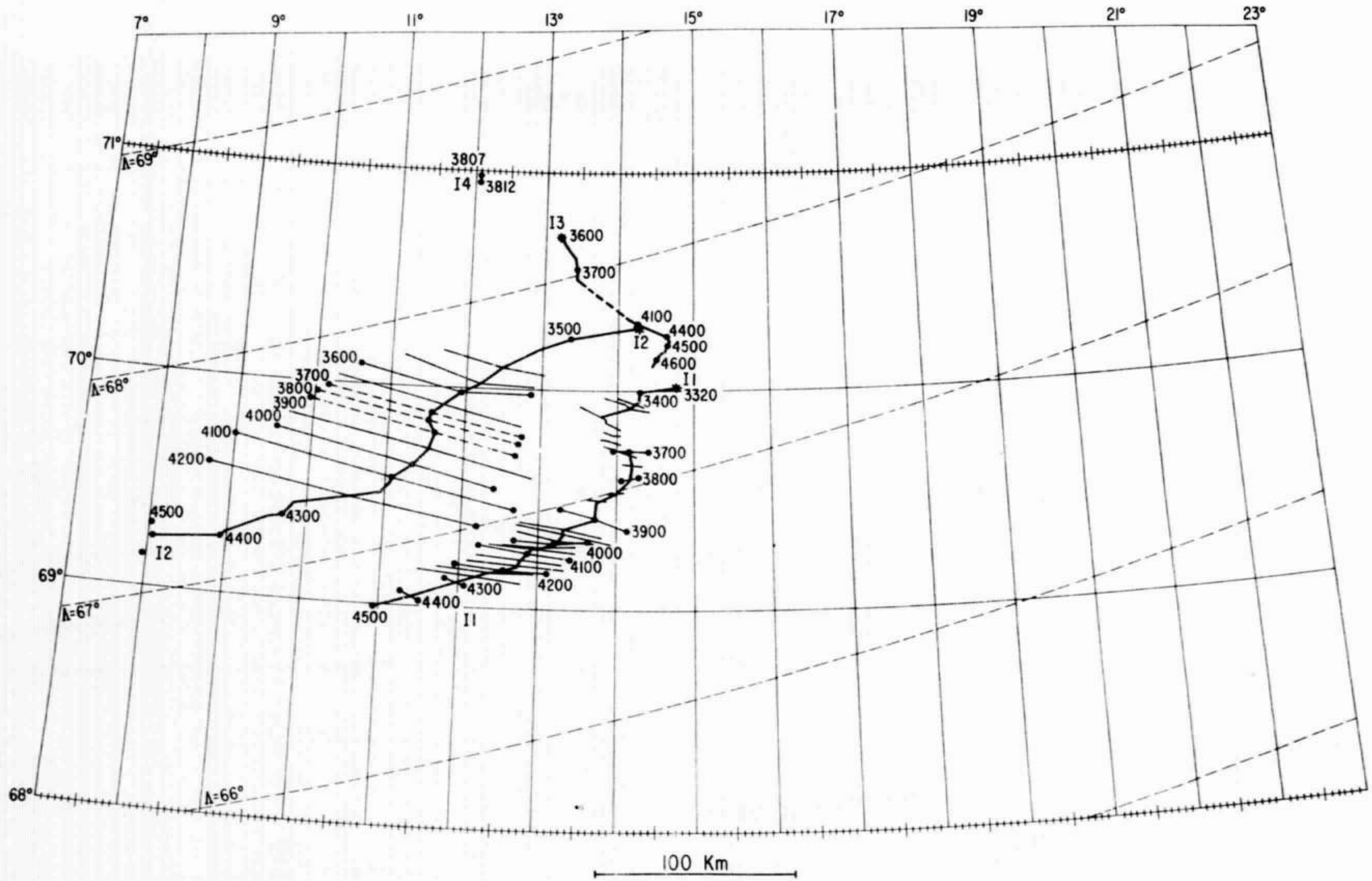
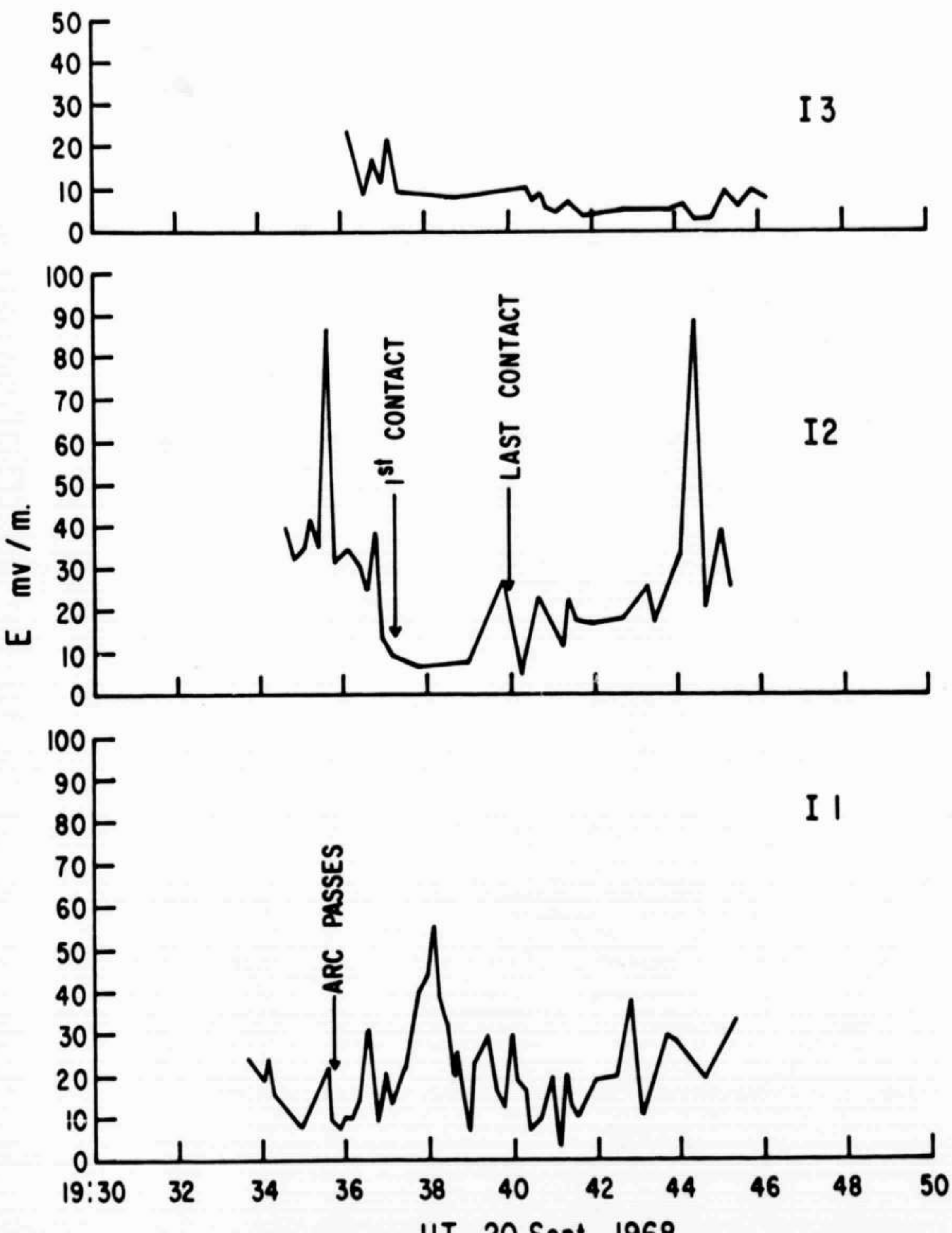

2211:15 UT
2212:00 UT
AURORAL PATCH
BRIGHT ARC
2212:30 UT
2217:20 UT
0
200 KM
1000 M/S
31 AUG 67

FIGURE 3



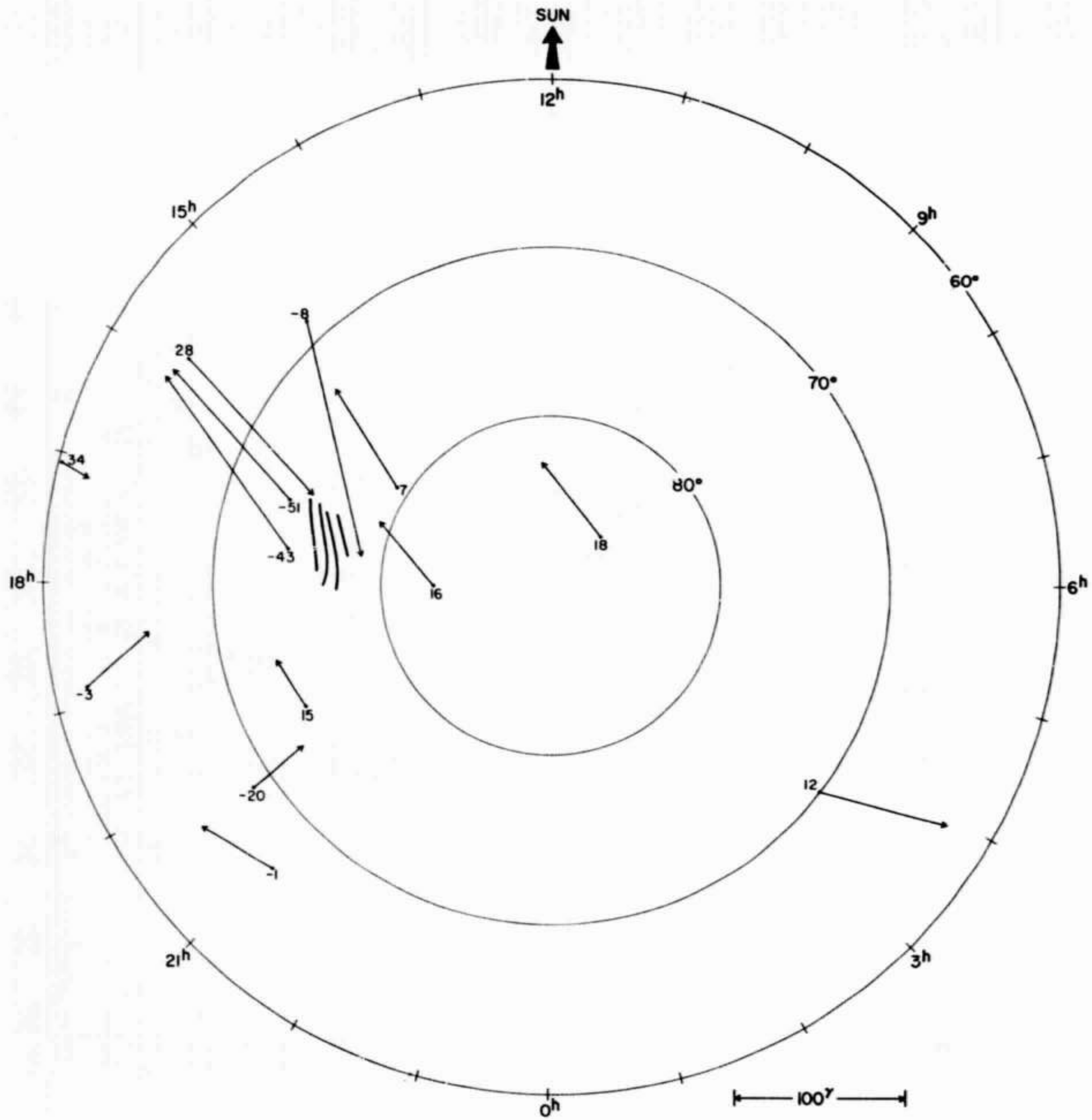
100 Km PROJECTED ION CLOUD TRACKS
20 SEPT., 1968

FIGURE 4



ELECTRIC FIELD MAGNITUDE PERPENDICULAR TO $\vec{B}$ vs. TIME FROM THREE IONIZED CLOUD MOTIONS.

FIGURE 5



SUN
12h
9h
60°
70°
80°
6h
3h
0h
21h
18h
15h
100γ
-8
28
34
7
-51
-43
18
16
-3
15
-20
12
-1

FIGURE 6

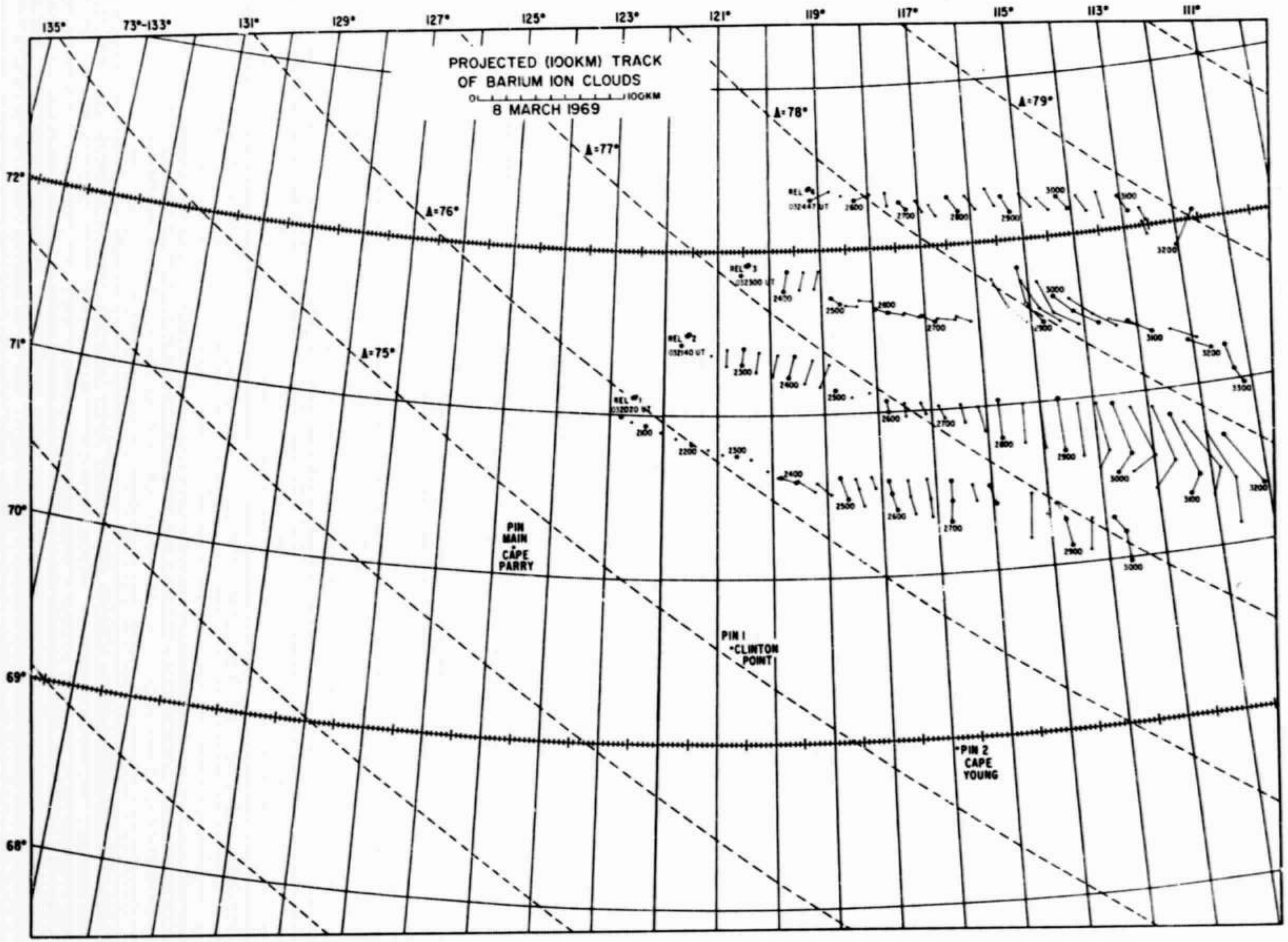


FIGURE 7

NASA-GSFC