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DYNAMICS OF MIDLATITUDE LIGHT ION TROUGH AND PLASMATAILS

A. J. CHEN
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AUGUST 1973

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

Light ion trough measurements near midnight made by the Bennett RF ion mass spectrometer on OGO 4 operating in the high resolution mode in February 1968 reveal the existence of irregular structure on the low latitude side of the mid-latitude trough. Using two different relations between the equatorial convection electric field, assumed spatially invariant and directed from dawn to dusk, and Kp (one based on plasmapause measurements, the other on polar cap E field measurements) a model development was made of the outer plasmasphere. The model calculations produced multiple plasmatail extensions of the plasmasphere which compare favorably with the observed irregularities. Due to magnetic local time differences between the northern and southern hemisphere along OGO's orbit, the time dependent irregularity structure observed is not symmetrical about the equator. The model development produces an outer plasmasphere boundary location which varies similarly to the observed minimum density point of the light ion trough. However the measurements are not extensive enough to yield conclusive proof that one of the electric field models is better than the other.

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*NAS-NRC Research Associate

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DYNAMICS OF MIDLATITUDE LIGHT ION TROUGH AND PLASMATAILS

INTRODUCTION

Previous studies of the midlatitude light ion trough have shown that the light ion trough is directly related to the equatorial plasmapause — both features occurring on or near the same field line (Carpenter et al., 1969; Taylor et al., 1969). However it has yet to be definitively determined whether there is any singular part in the light ion trough which is always identifiable as the plasmapause or whether the sharp equatorial plasmapause smears out at lower altitudes to form a more gradual decrease in light ion density with increasing L coordinate. Before such questions can be answered one must determine the thermal plasma density variations expected in the outer plasmasphere and look for signatures of such variations in the measured troughs.

Another feature of the light ion density distribution near the midlatitude trough is the known dependence of the latitudinal density variations upon solar-geomagnetic geometry (Taylor, 1972) with temporally varying fine structured patches of enhanced ionization induced by changes in the magnetic activity (Taylor et al., 1971). Since the trough is in a dynamic and yet spatially inhomogeneous state a single satellite's measurements must be complemented by other measurements or by a model to resolve the temporal and spatial variations.

This paper will use a magnetospheric convection model to show how the geometry of a satellite's orbit (in particular OGO 4) determines its view of the light ion trough and to show how structural features in the region of the trough as measured by the Bennett RF ion mass spectrometer on OGO 4 can readily be interpreted in terms of a dynamic model of the thermal plasma state in the outer plasmasphere.

DATA SELECTION

The latitudinal H^+ density profiles to be considered were measured by the Bennett RF ion mass spectrometer on the polar orbiting satellite OGO 4. With this spectrometer the option existed of operating in either a short sweep or long sweep mode. In the short sweep mode only the light ion densities were detected but the latitudinal spatial resolution was 0.2° in contrast to the long sweep mode in which all ionic masses were detected and the spatial resolution was only of the order of 2.3° of latitude. For a thorough study of the features of the light ion trough the short sweep data is more appropriate since, as was shown by Grebowsky et al. (1973) for the electron density trough, many of the structural features expected in the outer plasmasphere are small in spatial extent and hence easily undetectable by a polar orbiting low altitude satellite measurement with spatial resolution of the order of 1° latitude or more.

The OGO 4 RF spectrometer short sweep mode was operative for periods in September 1967 and February 1968. The September data was previously considered in a study by Taylor et al. (1971). Here aspects of the February 1968 high resolution H^+ density measurements in the region of the light ion trough will be explored.

Since more than 80 orbits with high resolution H^+ measurements were traversed by OGO 4 in February 1968, it is impractical to consider the details of the density profiles along each and every pass. Hence two particular sets of passes are singled out for consideration. The selected data sets consist of H^+ measurements obtained on five consecutive OGO 4 nightside passes on February 9-10, 1968 (Figure 1) and five consecutive passes on February 18, 1968 (Figure 2). For convenience in referencing, these measurements will be denoted Set I and Set II respectively. Since these measurements reveal characteristics similar to those observed on the other passes they are not to be considered unique occurrences. The dayside portions of these passes could not be studied since OGO 4 reached perigee well below the base of the protonosphere on the dayside of the earth resulting in poor quality H^+ measurements.

DENSITY VARIATIONS

The data Set I (Figure 1) shows the typical decrease in the midlatitude light ion density with increasing geomagnetic latitude associated with the low latitude side of the light ion trough. OGO 4 crossed the equator near 2300 LT on all the passes to be considered. The observed latitudinal H^+ density profiles are characterized by noiselike structure in the region of the trough — the more pronounced density enhancements are emphasized by shading.

If the patches of enhanced H^+ density are followed from pass to pass of OGO 4 comprising Set I, it becomes apparent that temporal and/or spatial variations dominate the observed thermal plasma distribution in the trough since the position and locations of each of the density spikes varies from orbit to orbit (the orbital period of OGO 4 is approximately 100 minutes). Indeed the observed irregular structure can even differ between the northern and southern hemisphere on the same satellite pass. Similar behavior is seen in the measurements comprising Set II (Figure 2) although the details, not unexpectedly, are different. Such structural features have also been seen near the plasmapause at higher altitudes (3000-5700 km) by electrostatic analyzers flown on the polar orbiting satellite OV3-1 (Bewersdorff and Sagolyn, 1972) and by the mass spectrometers on the near equatorial orbiting OGO 3 (Taylor et al., 1970) and OGO 5 (Chappell et al., 1970).

A previous study of structure in the H^+ density distribution in the light ion trough region was made by Taylor et al. (1971) who interpreted a prominent patch of enhanced ionization in the trough as a filamentary plasmatail extension of the plasmasphere drifting past the satellite's orbit. However the September 1967 event treated in that paper was a unique structure consisting of a solitary patch of enhanced ionization near midnight which arose following an intense magnetic storm; whereas, the February 1968 trough features considered here are more complex, with possible multiple patches of enhanced H^+ densities being observed on passes during continually agitated magnetic activity (the Kp variation at the time of the measurements is shown in Figure 3). Model studies were undertaken to determine whether the structure in the February 1968 trough measurements could be also attributed to plasmatail extensions of the plasmasphere.

MODEL

In order to determine the expected light ion density distribution along a satellite orbit it is necessary to know the past history of the magnetic flux tubes traversed by the satellite. The plasmapause formation is due to a transport of some magnetic flux tubes and their frozen-in plasma to the polar cap region where the field lines become open and light ions are rapidly lost, via the polar wind transport, to interplanetary (magnetotail) space. The density in a closed flux tube following such a depletion will increase with the length of time the flux tube remains closed and drifts through the sunlit ionosphere — the ionosphere being the source of plasma for the flux tubes. Hence ignoring the details of the filling up process, the average density in a flux tube is proportional to the dayside closure time and by following a flux tube backwards in time along its drift path this period can readily be computed. This approach was used with success by Grebowsky et al. (1973) to interpret measured midlatitude electron density trough variations.

For simplicity in the model calculations, the earth's magnetic field is assumed dipolar and field lines corresponding to L coordinates greater than 10 are assumed open — very little change in the computed closure times occurs by increasing the L coordinate corresponding to the open field line boundary due to the high drift velocities of thermal plasma at high L coordinates. The cross L drift of the thermal plasma and their frozen-in field lines is just the $\vec{E} \times \vec{B}$ drift where the electric field is a superposition of the corotation field and the convection electric field produced by the interaction between the solar wind and the magnetosphere. This latter field, the convection field, is assumed spatially invariant in the equatorial plane and directed from dawn to dusk while its magnitude varies with Kp.

The assumption of spatial invariance for the equatorial convection E field appears to be a good first approximation near the plasmapause (Chappell, 1973) although spatial variations must be included in higher order approximations due to the effects of nonuniform ionospheric electrical conductivities (Wolf, 1970) and the shielding of the Alfvén layer (Jaggi and Wolf, 1973). The use of the Kp index as an indicator of temporal changes in the convection field ignores the effects of temporal variations due to short term magnetic activity variations and the effects of some magnetic substorms since not all substorms are reflected in Kp variations. However since previous studies have produced consistent correlations between plasmapause-trough locations and Kp it is expected that Kp variations will give a more than adequate delineation of changes in the convection E field.

One simple spatially invariant equatorial convection E field model (Grebowsky et al., 1973) is based on the measured position of the plasmapause at dawn:

$$E = \frac{0.13}{(1 - 0.1\ Kp)^2}\ \mathrm{mv/m} \tag{1}$$

This dawn-dusk field was developed under the assumption that the derived steady state plasmapause (defined as the outermost closed streamline of the thermal plasma in the equatorial plane) at a fixed Kp near dawn corresponds to the average position measured at the same Kp by Biensack (1967). This model relies on measured plasmapause positions and suffers from the drawback that temporal phase differences (dependent upon local time) are known to exist between changes in the plasmapause location and changes in Kp (Chappell, 1972) whereas such phase differences and local time variations were not considered in arriving at (1). Also since the plasmapause position is causally dependent upon changes in the convection E field and not vice-versa, it would be more appealing from the physics standpoint to derive a similar relationship between the convection field and Kp which is independent of plasmapause measurements. From the recent results of direct electric field measurements this is now possible.

Electric field measurements on the OGO 6 satellite in the polar cap region revealed an average potential drop (Φ) across the polar cap dependent upon Kp (Heppner, personal communication) where:

$$\Phi\,(\text{kilovolts}) = 20 + 13.3\ \text{Kp}. \qquad (2)$$

Assuming an equatorial magnetosphere width of 25 Re in the dawn-dusk plane and assuming the entire polar cap potential drop is also dropped across the inner magnetosphere a simple expression relating E to Kp is obtained:

$$E = 0.125\ (1 + 2/3\ \text{Kp})\ \text{mv/m}. \qquad (3)$$

Both relations (1) and (3) will be used to interpret the light ion trough measurements in an attempt to determine whether the trough measurements can be used to deduce preperties of the magnetosphere convection pattern. It should be noted that the constant multiplicative factors in (1) and (3) can be modified without changing the resultant general topology of the plasmasphere. Such a change will only modify the scale size (Chen and Wolf, 1972).

MODELS AND MEASUREMENTS

First consider the state of the thermal plasma during the period of time encompassing data set one. If the magnetic flux tubes throughout the magnetosphere and their frozen-in plasma are followed backwards in time along their drift paths using the convection field described in Equation (1), the computed dayside closure times at the time of the OGO passes vary as shown in Figure 4. The closure times were determined at fixed universal times characterizing the first (Figure 4a) and the third (Figure 4b) orbits of data set one. Although the time it takes a flux tube to fill up to its equilibrium plasma density, after being depleted, varies from one day to the order of a week (Park, 1973) depending upon the L coordinate, it is assumed here that flux tubes attain their maximum content of plasma only after being closed for more than 6 days so that all possible structural variations can be explored. As the physics of the filling up process becomes better defined, the resultant profiles can easily be modified as some structural features are expected to be obscured — particularly at the lower L coordinates.

The computed closure times in Figure 4 are plotted in the equatorial plane so that field lines traversed by OGO 4 can be readily identified by using the L coordinate variation along the orbit. The complex structure in the dusk-midnight quadrant corresponding to distinct regions with different closure times reflects the sensitivity of the outer plasmasphere to the past history of magnetic activity. Plasmapause-like boundaries are expected between regions where the closure times change abruptly by more than one day signifying that the plasma density changes abruptly also, as pointed out by Grebowsky et al. (1973). At all such plasmapause transitions thin spikes of enhanced plasma density are also expected. That is, in Figure 4 and all such subsequent plots every line plotted, in addition to defining the closure time contours, also delineate flux tubes which have been closed and in daylight on more than six consecutive days. The structured region tends to corotate with the earth during the measurements as is expected since the measurements of data Set I took place during a period of relative magnetic quieting when the corotational drift dominates out to higher L coordinates.

The thin streamers of flux tubes with closure times greater than six days correspond to plasmatail extensions of the inner plasmasphere. The most prominent tail in this case is the outermost one. Whether some of the predicted tails are thin enough to smear out due to diffusion or to tear due to the effects of plasma instabilities has yet to be determined although the fine structure often seen in the midlatitude trough region, if indeed corresponding to plasmatails, implies that many such tails can exist at one time.

The projection of the OGO 4 trajectories on the model computation in Figure 4 shows that the premidnight portion of the OGO 4 pass (i.e., the southern hemisphere pass) should pass through the structured region before the postmidnight (i.e., northern hemisphere) portion of the pass due to the magnetic local time difference along the orbit between the two hemispheres. Indeed in Figure 1 a patch of enhanced ionization in the trough is definitely seen in the first orbit only in the southern hemisphere and is not observed in the H^+ measurements in the northern hemisphere until the second pass. However the model predicts that the tail structure should not be observed in the northern hemisphere until the third or fourth pass whereas it is definitely measured earlier. Such a lag between the model prediction and measured time of a plasmatail passage through midnight was also observed for the tail event seen in September 1967 by Taylor et al. (1971). Hence if the light ion trough density irregularities are indeed signatures of plasmatails then the convection electric field model requires modification. Using the newly defined E–Kp relationship in Equation (3) it will be seen that the lag between measured and modeled detection times of the cusp of the plasmatail can be reduced.

The computed dayside closure times for data Set I using the convection electric field variation defined in Equation (3) are shown in Figure 5. Since the orbit of

OGO 4 only samples magnetic local times between 2000 and 0100 hours the calculations were restricted to this window. Again each profile was computed at a fixed local time corresponding to a time near the midpoint of each OGO pass comprising Set I. The plasmatails computed tend to corotate with the earth with increasing time as with the previous model. Taking the corotation into account it is seen that the new model predicts that the cusp of the outermost plasmatail extension of the plasmasphere should be detected in the northern hemisphere (i.e., post midnight) on the second pass of OGO 4, in agreement with the observations in Figure 1. Hence the second model is in better agreement with the observations as far as the phase is concerned.

The general features of the light ion density measurements of Set I near the trough (Figure 1) are readily interpreted in terms of the model development shown in Figure 4. Observationally a thick patch of enhanced H^+ density is traversed in the trough on the first OGO pass only in the southern hemisphere in agreement with the model (Figure 4a). The observance of this plasmatail implies that dayside closure times of more than 6 days are required for the topside ionosphere H^+ density to attain its equilibrium values at L coordinates greater than 3 following depletion.

On the second and third OGO passes comprising Set I the observed patch of enhanced density tends to thin with time and is seen in both the northern and southern hemispheres. This is in agreement with the model (Figure 4b, 4c) remembering that the model was computed at a fixed universal time near the midpoint of each pass and that the computed plasmasphere structure tends to corotate with the earth with increasing universal time.

On the fourth and fifth OGO passes in Figure 1 multiple plasmapause-like decreases in H^+ density with increasing latitude are observed in the southern hemisphere with the high density patches of enhanced ionization, previously observed, not readily apparent. These northern hemisphere observations are in agreement with the model (Figure 4d, 4e) since it is predicted that OGO traversed two broad ranges of closure times near 5 and 6 days which will result in multiple plasmapause boundaries being detected. The plasmatails separating these regions may or may not be detectable since although the model predicts thin tails the model calculations, due to a compromise between accuracy and computing time, do not resolve tail thickness less than 0.1 Re in the equatorial plane. Due to the appearance of data gaps in the northern hemisphere on these passes, the comparison of model and measurements could not be extended to this hemisphere.

Another feature of the Set I trough structure can also be interpreted in terms of plasmatail evolutions. The density envelope of the thick patches of enhanced ionization observed on the first and record passes in Figure 1 show fine structured noiselike variations. The model plots in Figure 4a and Figure 4b on the other hand give the impression that only a broad unstructured plasmatail is traversed. However since this outer plasmatail is bounded by flux tubes which have been closed for the order of 6 days, it is a tail which was formed by a substorm 5-6 days before the measurements. Since the cusp of this tail attached to the inner plasmasphere tends to rotate with the earth while its equatorial endpoint remains fixed at the magnetopause in the noon-dusk quadrant, this outermost tail may have wrapped itself in spiral fashion around the earth a few times. Hence the outer tail may actually be comprised of closely spaced filamentary tails yielding a noiselike density structure (ignoring diffusion and instability effects).

Thus structural features observed on the low latitude side of the trough on the OGO4 passes comprising Set I appear to be interpretable in terms of a dynamic plasmasphere model. To be certain that this was not an exceptional case the data comprising Set II (Figure 2) taken during a more magnetically active period than Set I (see Figure 3) were also compared to the model.

The computed dayside closure times for the Set II measurements are plotted in Figure 5. The predicted structure in the outer plasmasphere is similar to that for Set I with the structured region again tending to corotate with the earth near midnight. Upon superimposing the OGO 4 trajectories on the computed profiles in Figure 5, it becomes evident that near symmetry of the light ion trough structure about the magnetic equator should exist except on the first pass where unfortunately a large data gap occurred in the southern hemisphere. However, in agreement with the model, on the orbit previous to the first pass of Set II (not shown) no broad patches of enhanced ionization were observed in the trough region. The model also predicts that a singular thick tail should be detected on the first and second orbits with two tails then becoming observable on the last three passes. Since the tails thin rapidly they may not be detectable on the subsequent passes. All of these features are in general agreement with observed trough structures in Figure 2. Hence the apparent H^+ density irregularities near the low latitude side of the midlatitude trough observed near midnight on February 18, 1968 are interpretable in terms of plasmatail development as was the case for the February 9-10, 1968 data discussed previously.

Due to the many simplifications made in the convection model — in particular, the assumption of a time independent dipole magnetic field configuration and the assumption of a spatially invariant equatorial convection electric field — the computed positions of the plasmatails are not expected to agree one-to-one with the observed positions and hence a direct comparison of the individual positions was not carried out. This is particularly true for the innermost tails since they are formed and affected by temporal variations occurring many days before the measurements with the resultant errors due to the approximations being accumulative over their lifetimes. However the position of the outermost boundary of the plasmasphere (i.e., the outer boundary of the outermost tail) is dependent upon only the most recent magnetic activity state and may lay in a region where the convection field may be described by a spatially invariant field. Hence this outermost boundary defined by the models may predict the observed motion of the outer plasmapause.

Since it is expected that the minimum position of the total electron density trough varies temporally in step with the plasmapause in the equatorial plane (Rycroft and Burnell, 1970; Grebowsky et al., 1973), and because the high latitude boundary of the outermost plasmatail inferred in the present study lies at or near the light ion trough minimum density point, the light ion trough minimum is probably on the average the near earth signature of the outermost plasmasphere boundary. From the physical viewpoint this appears reasonable since flux tubes outside of the plasmasphere have been recently depleted of plasma while auroral ionization effects will be confined to near and beyond the outer plasmapause if precipitation due to cyclotron resonance instabilities prevent the energetic auroral ionized particles from penetrating into the plasmasphere (see Brice and Lucas 1971 for a discussion of this precipitation mechanism).

To get a better idea of how well the models predict temporal changes in the trough position, the locations of the trough minima (when a definite minima is discernable below 65° geomagnetic latitude) on all of the February 1968 night time OGO passes when the spectrometer was in the high resolution mode were determined. These trough locations as plotted in Figure 6. The northern and southern hemisphere troughs are considered separately, since as shown previously, hemispherical differences in the trough location arise due to the variation of magnetic local time along the orbits of OGO 4. The Kp scale in Figure 6c is plotted with Kp increasing downward to emphasize the obvious correlation between decreasing values of Kp and increasing values of the trough's coordinate.

The outermost boundary of the plasmasphere at the universal time and local time at which a trough was detected by OGO4 was determined using both electric field models. The model calculations are superimposed on the measured trough positions in Figure 6. Both model calculations produce oscillatory motions in the boundary which roughly parallel the observed trough changes. Both models underestimate the L coordinate of the trough minimum with the electric field model based on Binsack's plasmapause measurements (Equation 1) yielding the better agreement. This however should not be construed as a convincing demonstration that the E-Kp functional form described in Equation (1) should be favored over that in Equation (3). Remaining within the uncertainty of the measurements used in deriving the field models, the convection field described in Equation (3) could be multiplied by a constant factor (the computed plasmapause L coordinate is scaled by the same factor) so that both models produce plasmapause L coordinates in similar agreement to the trough measurements.

This comparison demonstrates that either model with or without convective factors are only good average estimators of the trough position and neither stands apart from the other in reproducing the measurements. Further studies particularly simultaneous measurements are required before it can be definitely determined whether the trough minimum corresponds to the plasmapause, as assumed, or to determine details of the convection electric field variation. At best this comparison has shown that using Kp as the magnetic index depicting changes in the intensity of the magnetosphere convection is a good first approximation in determining the trough motion near midnight.

CONCLUSIONS

The midlatitude light ion trough at altitudes below 1000 kilometers is typically characterized by fine structured density variations on its low latitude side. Although noiselike variations in the latitudinal H^+ density profile at these altitudes can be expected due to the sporadic nature of auroral ionization at and above the latitude of the trough, many of the irregularities on the low latitude side can be interpreted as the near earth signature of thin filaments of relatively dense plasma in the equatorial plane. These equatorial filaments connect to the main body of the plasmasphere and the magnetopause to form tail-like extensions of the densely populated plasmasphere.

By considering the light ion density at any point in a magnetic flux tube to be roughly proportional to the period of time the flux tube has been closed and in daylight, the gross features of the plasma density variation in the outer plasmasphere can be determined by tracing equatorial plasma elements along their $\vec{E} \times \vec{B}$ drift paths. The convection E field was assumed spatially invariant and directed from dawn to dusk in the equatorial plane — a fair assumption in the light of current knowledge — and superimposed on the corotation drift. The convection E field magnitude was varied in step with Kp to reflect the dependency between world wide magnetic activity and the flow of plasma. Two different relations were used for this variation, one based on Binsack's plasmapause measurements and the other based on polar cap electric field measurements by Heppner. Both models, particularly the second, produced plasmatails which crossed the OGO 4 orbital path when patches of enhanced plasma density were detected. Other than this agreement however, the measurements did not favor one model over the other but showed that coincident plasmapause-trough measurements would be required to determine which model best was best or to determine what modifications are required in the models to better approximate reality. From the physical viewpoint however the model based on electric field measurements is more satisfying as it is based on clearly defined and directly measurable quantities.

The model calculations show that the detection of plasmatail density enhancements on a polar orbiting satellite such as OGO 4 is complicated by the geometry of the satellite orbit itself. Due to temporal and spatial variations in the plasmatail configuration caused by magnetic activity variations and the changes in magnetic local time along a satellite orbit, the observed light ion trough density irregularities associated with plasmatails are not symmetrically detected about the equator but are sometimes observed in only one hemisphere on a given satellite pass. The existence of plasmatails and hence multiple plasmapauses are also seen to be the rule rather than the exception.

The position of the minimum density point in the light ion trough appears to be a good indicator of the dynamic motion in the outer plasmasphere with the trough moving towards lower latitudes near midnight with an increase in magnetic activity. The outermost plasmasphere boundary as computed by the dynamic models and the minimum position tend to vary in step with one another, but further experiments are needed to determine whether the minimum of the trough and the outermost plasmapause are always near the same field lines. For studying gross changes in the intensity of the magnetosphere convection the trough minimum is a useful point to follow.

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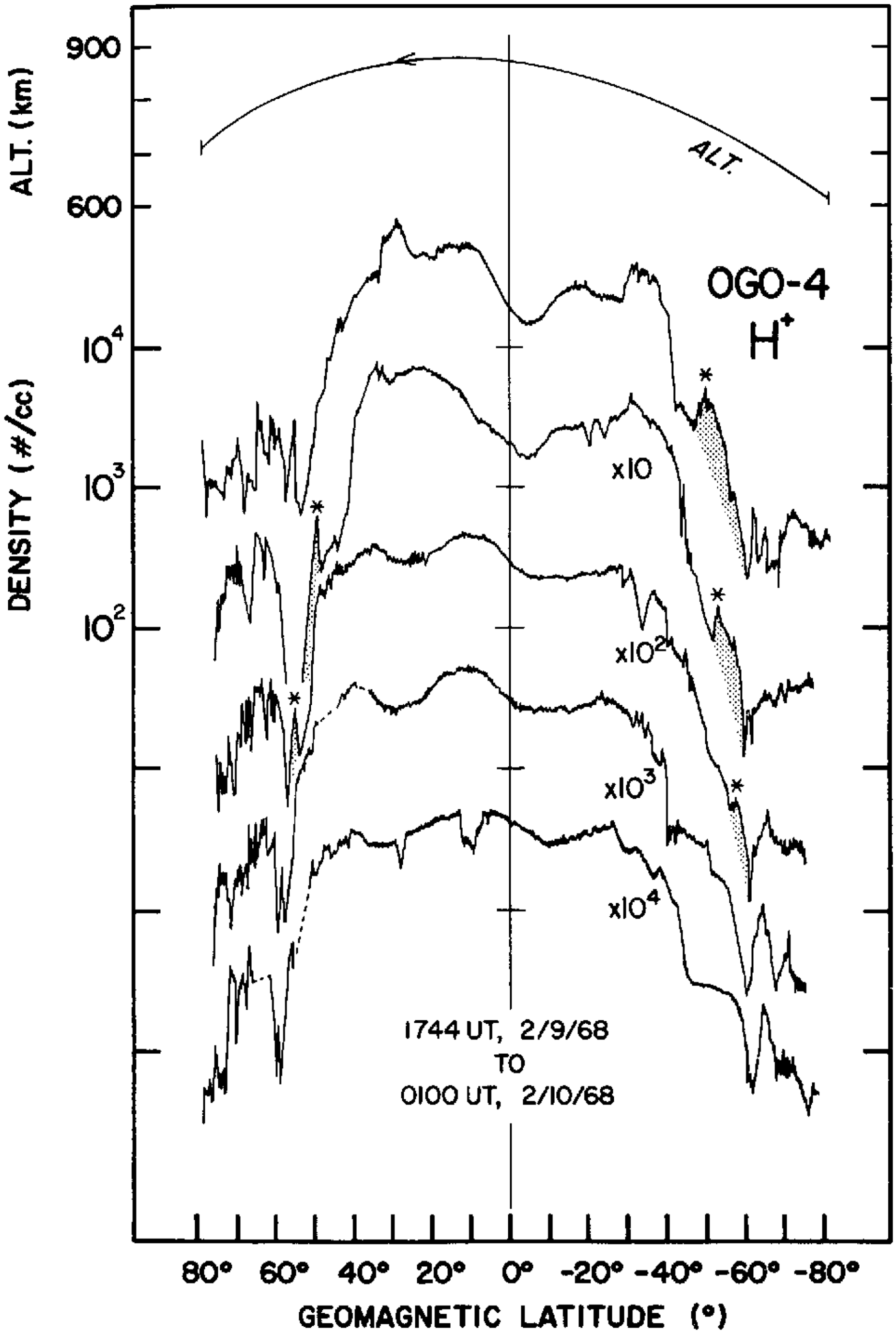


Figure 1. Data Set I: H^+ density measurements on five consecutive OGO 4 passes near midnight on February 9, 10, 1968. Each consecutive orbit (from top to bottom) is plotted on a scale displaced downward a factor of 10 from the previous orbit. The most distinct structural features which may be identified with filamentary extensions of the plasmasphere are marked by asterisks and shadings.

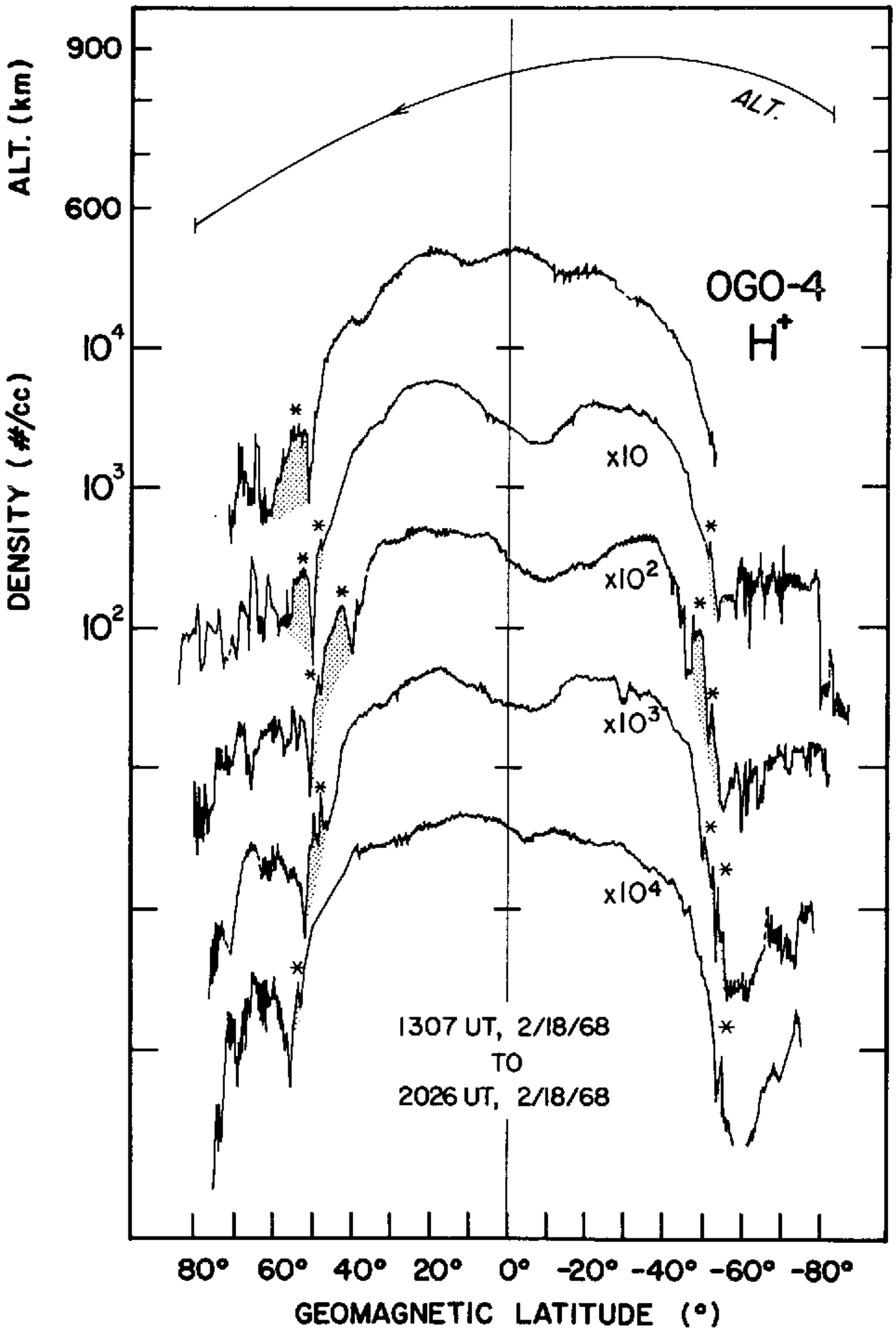


Figure 2. Data Set II: H^+ density measurements on five consecutive OGO 4 passes near midnight on February 18, 1968. Each consecutive orbit (from top to bottom) is plotted on a scale displaced downward a factor of 10 from the previous orbit. The structural features likely to be associated with filamentary extensions of the plasmasphere are marked by asterisks and shading.

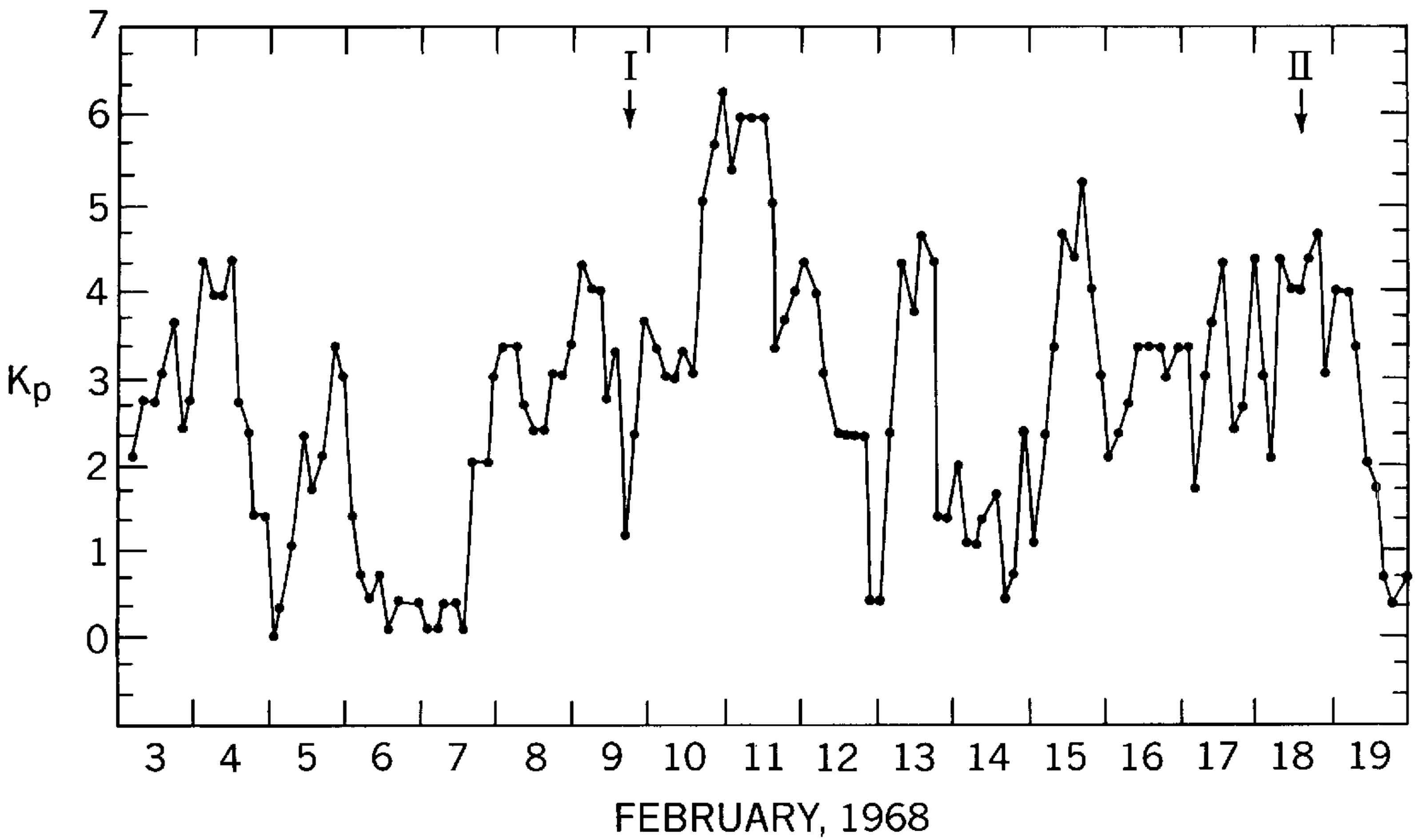
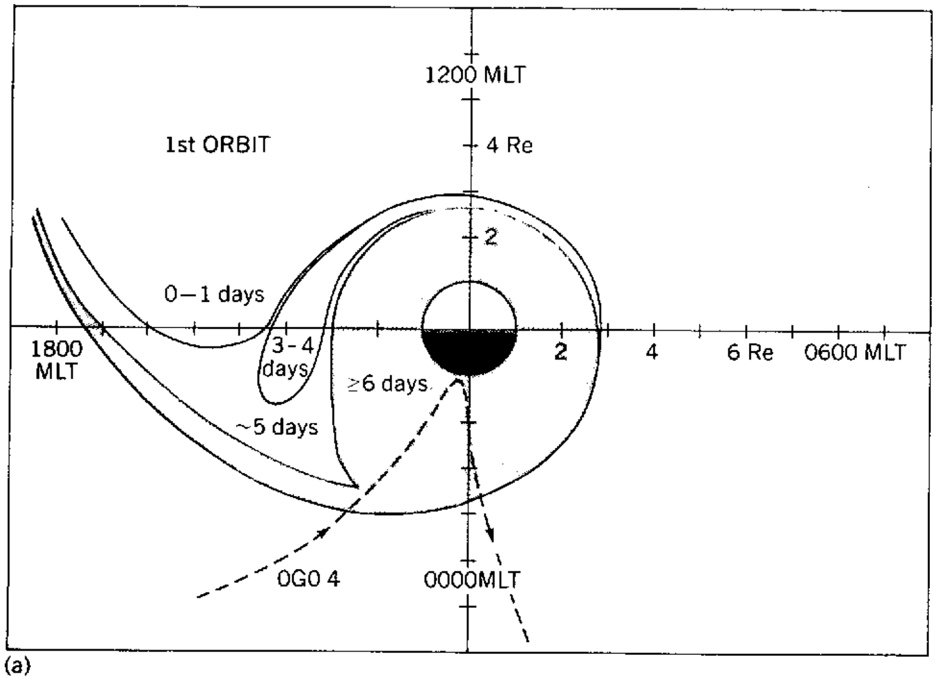


Figure 3. The Kp variation is shown for the period of the OGO 4 measurements under investigation. The location of data Sets I and II with respect to magnetic activity are indicated. Set I occurred after a substorm whereas II took place in the midst of agitated magnetic activity.



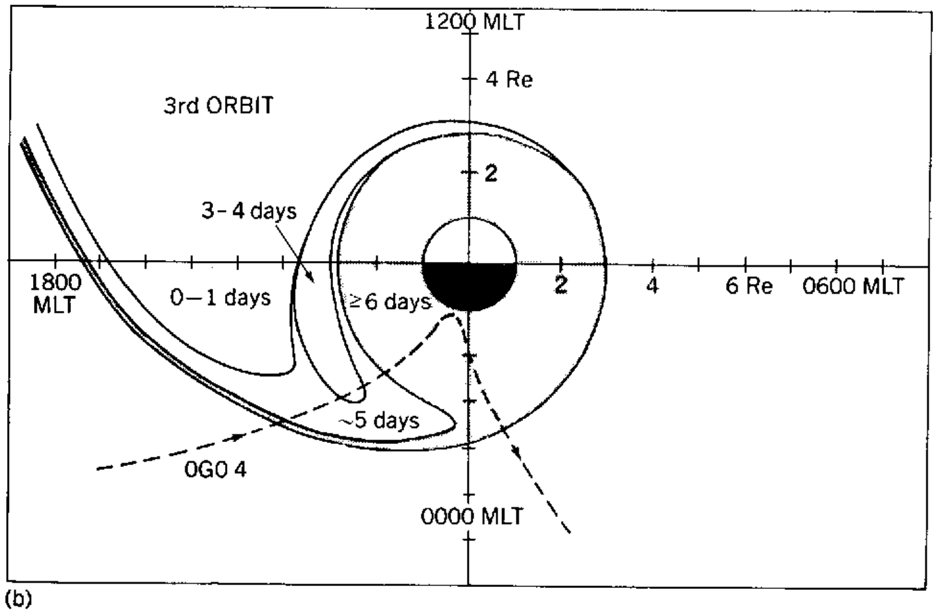


Figure 4. Dayside closure times in the equatorial plane using the convection electric field model based on Binsack's plasmapause are plotted for universal times characterizing the midpoints of the first and third orbits of data Set I. Due to the magnetic local time variation along the OGO 4 orbit projected in terms of L coordinates a distinct hemispherical asymmetry is expected. The entire outer plasmasphere structure tends to corotate with the earth during this period of time.

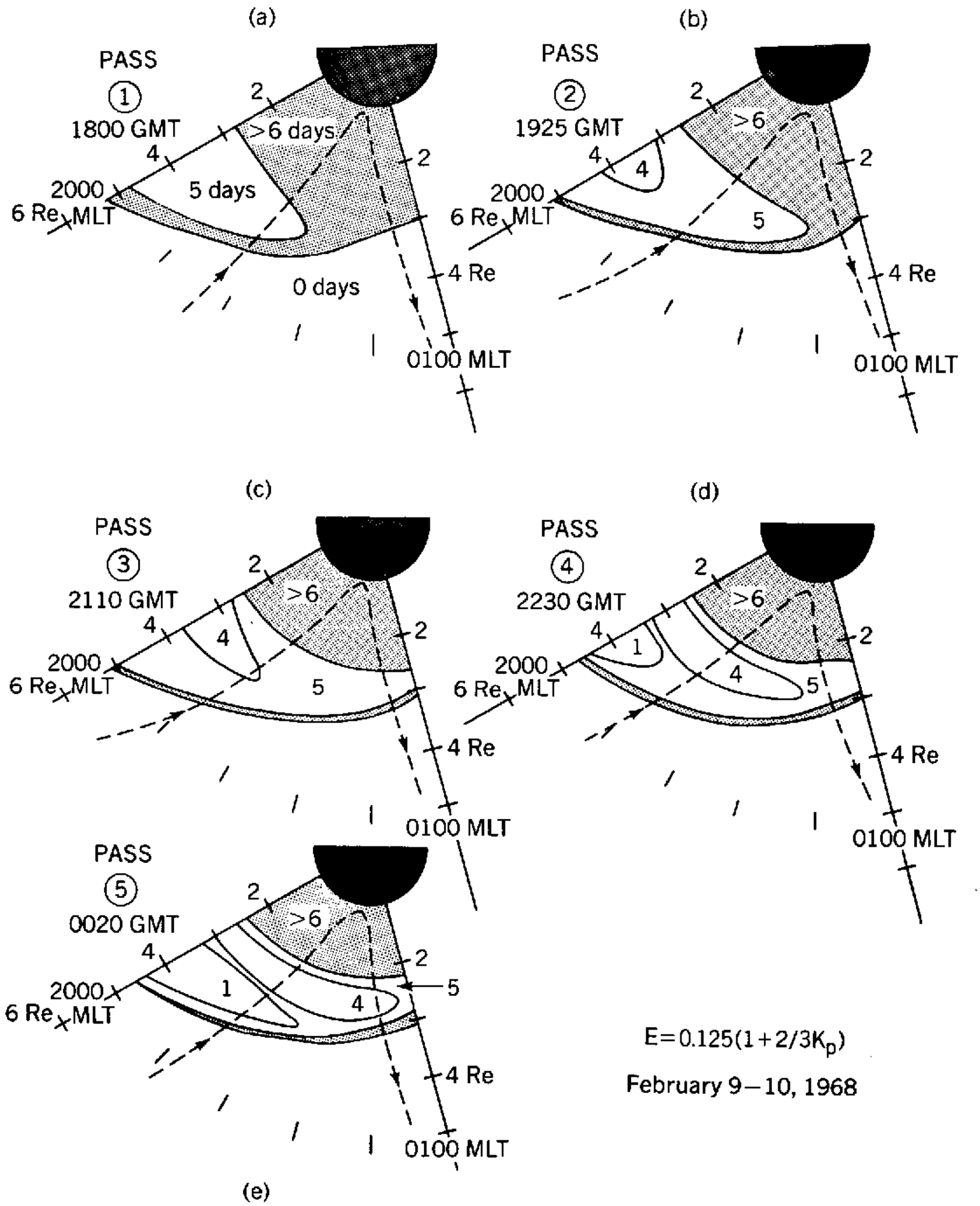


Figure 5. Dayside closure times in the magnetic local time sector between 2000 MLT and 0100 MLT are plotted at universal times characterizing the midpoints of each consecutive pass (in directions of increasing numbers) of data Set I. The orbit of OGO 4 is superimposed by considering the L-MLT variation along the satellite orbit. Multiple plasmapauses and tails are expected to be traversed. The convection electric field model derived from polar cap electric field measurements was used.

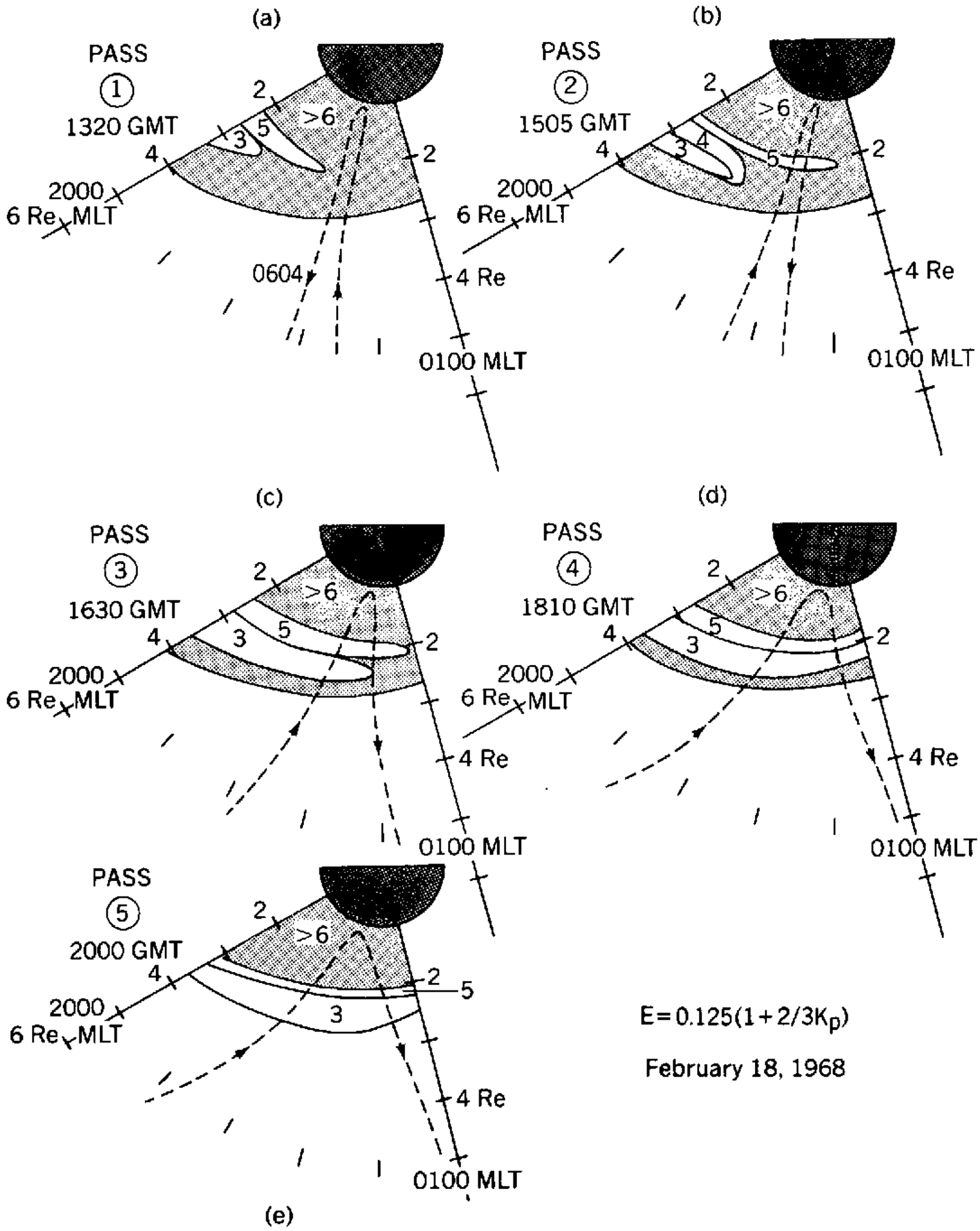


Figure 6. Dayside closure times at the equator in a magnetic local time sector encompassing OGO 4's trajectory are plotted at universal times characterizing each successive pass of data Set II. The convection electric field model based on polar cap measurements was used. The complex outer plasmasphere structure tends to corotate with the earth in this dusk-midnight sector although changes in the L positions of the structure does occur due to varying magnetic activity.

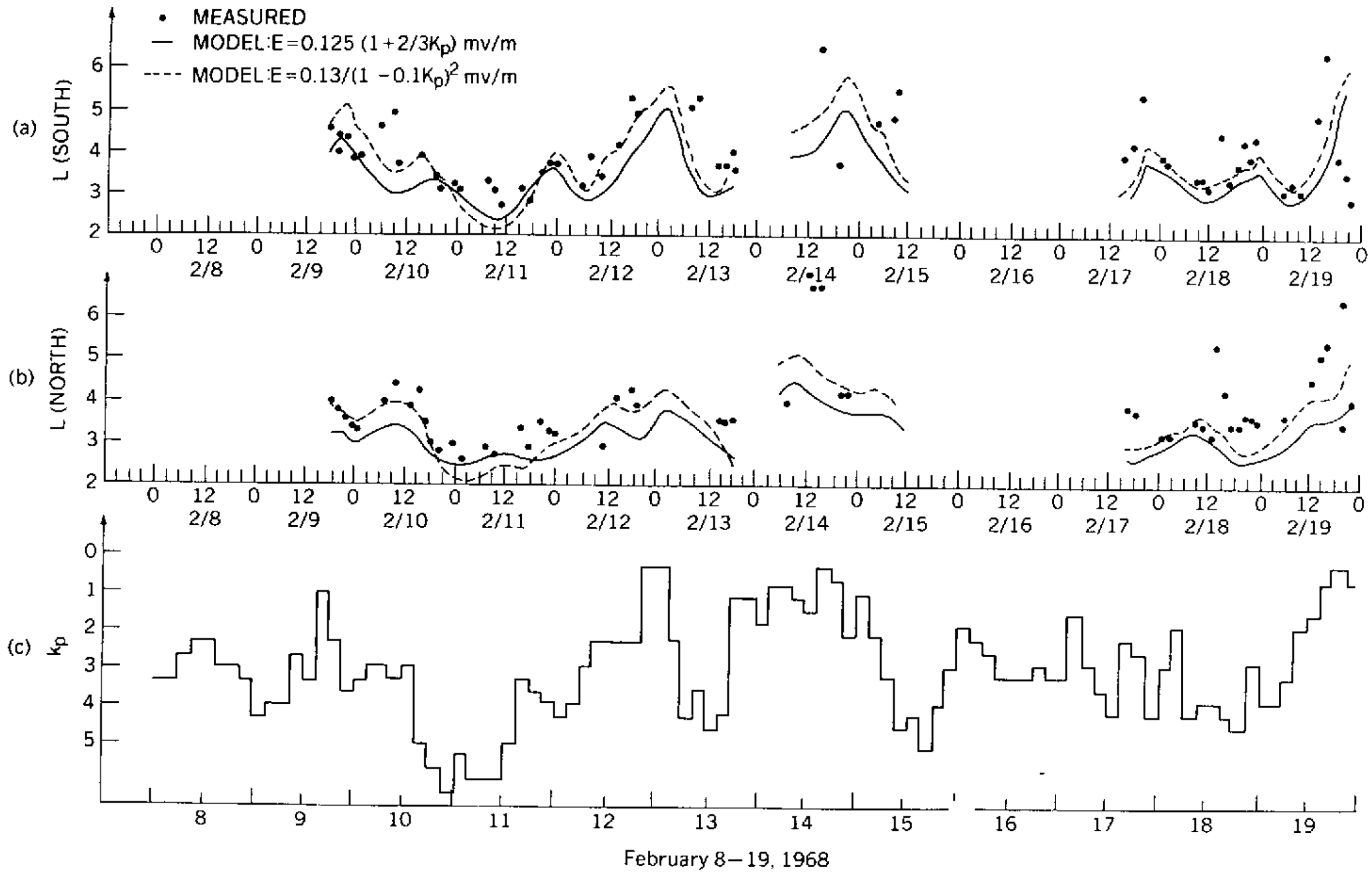


Figure 7. (a) The OGO 4 measured trough minimum position is plotted against universal time for the southern hemisphere with the predicted model variations superimposed. The general behavior of the trough minimum is reproduced by both models. — (b) The measured trough minima locations for the northern hemisphere passes is followed in a gross sense by the model evaluation of the outer plasmasphere boundary motion. — (c) The Kp index is plotted with increasing values downward to show the evident correlation between decreases in Kp and a motion of the trough minimum (and predicted outer plasmasphere boundary) to higher L coordinates. — The near earth measurements were traced along the field lines to the equator using the most recent spherical harmonic expansion of the earth's magnetic field as deduced from POGO data (R. Langel, personal communication).