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ABSTRACT

Ion composition results obtained from the polar orbiting OGO-4 satellite during 1967-68 reveal a pronounced longitudinal variation in the composition of the topside ionosphere. This variation is in the form of a large scale wobble or shift in the latitudinal distributions of the major topside ions H^+, O^+, He^+, and N^+, observed as the earth rotates beneath the fixed satellite orbit. Both the location and prominence of distinct ionospheric features, including the O^+-H^+ transition level, the H^+/He^+ ratio, the high latitude depletion of H^+ and He^+, and the winter bulge in He^+, are found to change significantly between longitudes for which the angle between the earth-sun line and the dipole equator has its greatest variation. Similarly, it is found that the ambient ion concentrations at a given latitude may change by as much as an order of magnitude between contrasting longitudes, even though the altitude and magnetic activity remain nearly constant. The overall result is that seasonal variations, such as the decrease in production of ionization at winter latitudes, are maximized at the location of extreme "solar-magnetic season". The persistence of the longitudinal asymmetry over a range of local times, seasons, and magnetic conditions reveals that the topside ionosphere is dependent upon a solar magnetic rather than simply a solar seasonal control. This variation, which may involve large scale transport of both ions and neutral

particles, presents an added complication to studies of the topside ionosphere. These results indicate that investigations of both long and short term changes in the ion composition must, to be rigorous, take into consideration the solar geomagnetic seasonal effects.

CONTENTS

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INTRODUCTION

The successful flights of the polar orbiting geophysical observatories, OGO's 2, 4 and 6, have provided a unique opportunity for exploring the composition of the topside ionosphere. Combining a near polar orbit with a continuous high-rate data acquisition capability, these satellites have made possible a detailed survey of the topside composition with a resolution in time and position unequalled by earlier direct measurement efforts. As a result, it has been possible to obtain, for the first time, continuous pole-to-pole profiles of the ion composition over periods of days and weeks. Such results have yielded evidence of dramatic latitudinal variations in the topside composition including the high latitude light ion trough in H^+ and He^+ which has been associated with the plasmapause [Taylor et al., 1968] [Taylor et al., 1969], and the winter-time bulge and equatorial trough in He^+ [Taylor et al., 1969b]. The latitudinal features are superimposed upon a global pattern of composition in which H^+, O^+, He^+ and N^+ ions dominate the topside ionosphere, with a tendancy for the lighter ions to be prevalent in the equatorial regions and the heavier ions to populate the polar regions [Taylor et al., 1968]. These results are in general agreement with other direct [Hoffman, 1967] and indirect [Thomas et al., 1966] [Shawhan and Gurnett, 1966] [Carlson and Gordon, 1966] [Barrington et al., 1965] measurement studies.

Recently, more intensive studies of data available from the OGO-4 satellite have revealed that a strong longitudinal variation is superimposed upon the previously described latitudinal variations in the composition. In general, the longitudinal variation is in the form of a large scale shift or 'wobble' in the ion distributions, and has been observed throughout the composition in both atomic and molecular species [Taylor et al., 1969b]. In this paper, the longitudinal variation of the primary topside ions is examined in detail, for conditions of northern hemisphere summer and noon local time. These results are subsequently compared with data obtained for a contrasting season, and the resulting implications of a solar-magnetic seasonal control of the ionosphere are described.

The ion composition data were obtained with a Bennett radio frequency ion mass spectrometer experiment which measures ambient thermal positive ions in the mass range 1-45 AMU. Experiment description as well as preliminary results have been given in earlier papers [Taylor et al., 1968] [Brinton et al., 1968].

RESULTS

Selection of the Data Sample

Most of the data to be discussed were obtained from OGO-4 during 1967-68, from a near polar orbit (inclination near 83.5°) with an initial perigee of about 412 km. and an apogee of about 908 km. The orbital period was approximately 105 minutes so that pole-to-pole ion composition profiles were recorded with a longitudinal resolution of about 24°. Thus a sampling of the complete longitude range is accomplished within 15 consecutive orbits, requiring a period of about 26 hours. Complete longitude samples are, however, usually interrupted by switching of the spacecraft data acquisition system so that in general, the ion composition is sampled continuously for a 2 day period, off for 2 days, on for two days, etc., in a periodic fashion.

Two key factors influencing the selection of comparison data are (1) the motion of perigee/apogee and (2) the formation of magnetic substorms. Because of the strong influence of both altitude and the geomagnetic field upon the distribution of the ionization, it is most desirable to examine the ion profiles as a function of dipole latitude. Due to orbital precession, the geographic latitude of apogee changes by -3.4° per day. During the course of one earth rotation, this motion, coupled with the relative nutation between the geographic and dipole coordinate systems, results, during one day, in a variation of as much as 25° dipole latitude in the location of a given altitude sector of the orbit. Accordingly, in order to compare ion profiles observed at <u>similar</u> longitudes (within $\pm$ 24°), and at nearly equivalent altitudes and dipole latitudes, data must be selected allowing a time spacing of approximately 1 day. Similarly, data at <u>contrasting</u> longitudes (>±100°) may be obtained with a time spacing of about 12 hours.

The above time/location selection process is in turn influenced by magnetic storm activity. Since magnetic substorms frequently occur with spacings of 4-6 days, it is rather difficult to find homogeneous "quiet" or "disturbed" periods within which results at similar and contrasting longitudes may be obtained. Accordingly, the data sample selected for this study is the result of a unique and highly selective process.

In order to make our results most representative of topside conditions, and further, to minimize the significance of altitude variations, we have further restricted the data sample to the apogee side of the orbit, with the added requirement that apogee be aligned within about $\pm$ 30° of the dipole equator. In this way, we obtain near symmetry in the altitude latitude relationship, and thus the longitudinal variation may be identified most clearly.

Overall, the above requirements significantly restrict the quantity of the data sample available for data study. This is in part illustrated in Figure 1, which displays the time history of variation of apogee with respect to dipole latitude, and local time. As shown, apogee-dipole equator crossings are spaced at intervals of 51 days, and about 7 hours local time. Thus, the opportunity for comparing apogee-equator data for different seasons at the same local time does not exist. Therefore, we have selected data from May and December, 1968 for a comparison of summer and winter seasonal effects, respectively, even though the local time necessarily shifts from noon to late afternoon, with a difference of about 5 hours local time.

Local Noon-Northern Hemisphere Summer Ion Profiles

A series of ion concentration profiles representative of local noon northern hemisphere summertime conditions is presented in Figure 2 a-d. These profiles have been selected as a "family" to illustrate the global longitudinal variation in the composition, observed over the shortest possible universal time period. Importantly, the period of these observations, May 26-28, 1968, is magnetically quiet, with Kp remaining below the level of 2 for much of the time.

(1) O^+ and N^+ Profiles

From Figure 2a and b, it may be seen that both the O^+ and N^+ distributions exhibit a pronounced seasonal asymmetry, with a bulge or enhancement in the summer hemisphere and a relative depletion in the winter hemisphere. The winter depletion is further emphasized by a rather abrupt and sometimes structured high latitude trough, which in turn is most prominent at mid-negative longitudes. The poleward edge of the trough is usually marked by a rapidly rising high latitude peak, wherein the ion concentrations may return to levels similar to those observed at mid and low latitudes.

The influence of a "solar magnetic season" is suggested by the correlation between the gradual wobble or shift in both the O^+ and N^+ distributions and the amplitude variation of the angle α, which is defined as the angle between the plane of the dipole equator and the earth-sun line, measured at the time when the satellite crosses the dipole equator. (At the local time of these data, near the noon meridian, α is essentially two dimensional. At other local times the geometry takes on a third dimension and α is more difficult to visualize. For simplicity, however, the 2 dimensional form is retained in this study). It is clear that for maximum values of α, corresponding to the extreme positions for the solar magnetic season, the asymmetry in both the O^+ and N^+ distributions with dipole latitude is most pronounced. Although some additional second order variations occur in the concentrations from pass to pass, the overall solar magnetic shift in the profiles is well identified, with summer hemisphere concentrations exceeding winter concentrations by as much as a factor of 5-10 at comparable mid and high latitudes. In general, the N^+ distributions rather closely parallel those of O^+, with $n(O^+)/n(N^+) \approx 25:1$.

(2) H^+ and He^+ Profiles

The longitudinal variation in the H^+ and He^+ distributions, observed simultaneously with those of O^+ and N^+, is illustrated in Figure 2, c and d. Of the two, the H^+ distributions are considerably more regular in terms of both longitudinal and latitudinal variations. In general, H^+ exhibits a relatively symmetric latitudinal variation at longitudes for which the solar magnetic season is least pronounced. Conversely, for maximum values of α, a major winter hemisphere depletion of H^+ begins at mid latitudes, extending to a very pronounced trough at high latitudes, followed by a recovery toward the pole. In contrast, the summer hemisphere distributions of H^+ exhibit much less pronounced variation with longitude.

Relative to the other ions, the distributions of He^+ appear to be somewhat more complex in terms of both latitudinal and longitudinal variations. In Figure 2 d, the He^+ profiles exhibit three distinct features:

(1) an abrupt high latitude trough which is most pronounced at maximum solar magnetic winter positions,

(2) a seasonal asymmetry, in which the winter hemisphere concentrations are enhanced relative to those at comparable latitudes in the summer hemisphere and,

(3) an equatorial trough in which the He^+ concentration decreases by as much as a factor of 5 relative to its mid latitude concentration levels.

Because of the pronounced latitudinal and longitudinal variations in He^+, it is difficult to determine even an average factor for the ratio H^+/He^+. Clearly, these light ions are not distributed in concentric layers in the topside ionosphere, but rather exhibit a relative concentration which varies almost continuously with latitude and longitude. In the summer hemisphere, near noon, the concentration of H^+ is generally at least a factor of 5-10 higher than that of He^+. In the winter hemisphere, however, the situation is considerably more variable and at maximum solar magnetic winter positions, the concentration of He^+ sometimes exceeds that of H^+, over narrow ranges of latitude.

<u>Seasonal Variations</u>

(1) <u>The O^+/H^+ Ratio and the Transition Level</u>

In order to study the above features of the longitudinal variation in more detail, we now examine ion concentration profiles observed at contrasting longitudes within the May family. As the first of these features, we choose the O^+/H^+ ratio, as indicative of the large scale distribution of the ionosphere. In Figure 3, we compare two sets of O^+ and H^+ profiles obtained at contrasting longitudes (134° and -75°) on May 26 and May 28, respectively. At 134° lg., $\alpha = 10°$, the transition level is not encountered, since it is located above the altitude of the orbit, at all latitudes. In this case, throughout the altitude range of about 620-880 km, the concentration of O^+ is observed to be at least a factor of 5 greater than the concentration of H^+, at all latitudes. At the contrasting longitude -75°, α =33°, the southern hemisphere distributions of both O^+ and H^+ are greatly modified and the transition level is encountered between -30 and -40° latitude in the altitude range of 800-830 km. Significantly, for the same altitude and latitude at the α = 10° position, $n(O^+)$ exceeds $n(H^+)$ by a factor of 5! Thus, it is apparent that if sounding rocket probes were made from these contrasting longitude positions, the results on the transition level could be quite misleading, in absence of knowledge of the longitudinal variation.

To verify the persistence of the solar-geomagnetic season, we now examine data obtained at a contrasting season in December, 1968. In Figure 4, O^+ and H^+ profiles obtained on May 27 at -93° lg., α = 32°, are compared with profiles obtained on December 12 at -95° lg., α = -12.5°. Although the summer hemisphere distributions of O^+ and H^+ are rather similar for the two periods, the distinct disagreement between the profiles observed in the winter hemisphere is quite evident, with the strong wintertime depletion typical of the May data being essentially filled-in in the December data. Thus, although the transition level is encountered near -30° and 825 km in the May data, O^+ remains the dominant ion throughout the altitude range of 500-830 km during December and the transition level is never encountered at this longitude. Accordingly, the apparent seasonal difference observed between the May and December periods would seem to be the absence of the pronounced ion depletion in the winter hemisphere. However, it is noted that while we have compared data at nearly identical longitudes, and thus presumably have eliminated longitude as a variable, the amplitude of the angle α is, quite naturally, considerably different at this position for the two contrasting seasons. Thus, it is clear that we have not compared nearly identical solar-geomagnetic seasons but rather have simply compared the usual solar seasonal relationship.

In Figure 5, we identify as closely as possible, the true solar-geomagnetic seasonal variation occurring in the O^+/H^+ ratio between May and December. In the left-hand panel the strong seasonal variation observed in May is shown with profiles obtained at -75° lg., $\alpha = +33°$, which were used earlier in Figure 3. In the right-hand panel, ion profiles obtained at 75° lg., $\alpha = -33°$, reveal a distinct similarity with those obtained in May. The significant point is that the December data are selected at a longitude widely <u>different</u> from that chosen for May, in order to obtain the same value for α (33°) and thus, the similar solar-geomagnetic season. Considering that the local time positions are distinctly different, and further that the solar seasonal conditions are not purely opposed for these data, the similarity in the sets of profiles is remarkably good. Although the transition level is not encountered in the December profiles, the strong winter hemisphere depletion and polar enhancement are well reproduced, and a close examination of large quantities of data suggests that, at a slightly different solar-geomagnetic seasonal position in December, the opposing hemisphere symmetry could likely be observed.

(2) The H^+/He^+ Ratio

As shown in Figure 2, the latitudinal profiles of both H^+ and He^+ exhibit a considerable variability with longitude. This variability is such that the ratio H^+/He^+ constantly varies with both latitude and longitude, so that it becomes impractical to identify a meaningful single factor to describe the global variation between these two light ions.

In figure 6, the pronounced variation in H^+/He^+ observed at contrasting solar-geomagnetic positions is examined for data obtained on May 26 and 28, 1968. At the 134° lg., $\alpha = 10°$, position, H^+ exceeds He^+ at all latitudes, throughout the altitude range 600-850 km., and the ratio H^+/He^+ varies in a quite irregular pattern, with a maximum of about 30:1 near the equator and a minimum of about 2:1 at mid and high southern latitudes in the winter hemisphere. The broad and pronounced equatorial trough in He^+, extending between about 20°N and 20°S is a primary factor contributing to the variability in the H^+/He^+ ratio.

In contrast, the data obtained at the -51° longitude $\alpha = 33°$ position, reveal a considerably different pattern in the distributions of the light ions. At this extreme solar-geomagnetic position, the equatorial trough in He^+ has broadened and flattened somewhat, and the ratio H^+/He^+ remains as high as at least 10:1 throughout the summer hemisphere and at low latitudes in the winter hemisphere. However, beyond about 30°S the concentration of H^+ is rapidly depleted, forming a major trough near 65° S, while the concentration of He^+ continues relatively undiminished until an abrupt decrease near 75°S. As a result, the H^+ and He^+ concentrations rapidly converge near 45°S and between 45° and 75°S, He^+ becomes the major light ion, and over a relatively narrow latitude range near 67°S, He^+ exceeds H^+ by nearly an order of magnitude.

To further examine the solar-geomagnetic seasonal variation in H^+/He^+, we next compare light ion profiles obtained in May with those obtained in December. In figure 7, we compare data obtained in May at -75° lg., α = 33°, with data obtained in December at +75° lg., α = -33°. In this case, we observe that the general features of the light ion distributions are rather similar, in that the latitudinal asymmetries are reversed in accord with the seasonal asymmetries. In particular, the H^+ distribution is consistently comparatively higher in the summer hemisphere, peaks near the equator, and falls off rapidly toward a major trough in the vicinity of 60-70° in the winter hemisphere. The He^+ distributions are consistently low in the summer hemisphere, exhibit a broad and variable depletion across the equatorial region, followed by a seasonal asymmetry or bulge favoring the winter hemisphere, and finally show abrupt depletions at high latitudes. At both locations, the H^+/He^+ ratio remains consistently high, except at mid to high winter latitudes, where the light ion distributions rapidly converge. Although He^+ does, in fact, exceed H^+ in the winter hemisphere during May, the December data show that H^+ remains the dominant light ion, although the ratio does decrease significantly in the winter hemisphere. It should be noted that at the extreme solar-geomagnetic seasonal position in May

(α = 33°) the H^+ trough near 70°S in the winter hemisphere is not accompanied by a similar trough in He^+, whereas at the comparable α position in December, near 1700 L.T., a similar and simultaneous trough is formed in both H^+ and He^+ near 65° in the winter hemisphere.

Although space cannot be taken to show all of the supporting data obtained in the December data set, these data reveal that the best correlation in the seasonal variation of the light ions is in fact, observed at the comparable solar-geomagnetic position (α = $\pm$ 33°) as was true in the comparison of the O^+-H^+ transition level data. Thus, a comparison of the May-December variation in the H^+/He^+ distribution at a fixed longitude would provide completely misleading results. This fact is documented in Figure 8, where the H^+ and He^+ distributions observed in May at -93° lg., α = 32°, are compared with profiles observed in December at -95° lg., α = -12.5°. While the general characteristics of the H^+ and He^+ profiles observed at -93° are comparable to those observed during May at -75° (see Figure 7) these characteristics are distinctly different from those observed at -95° in December. It should be noted that in general, for the α = -12.5° position, where the solar-geomagnetic seasonal geometry is least pronounced, the seasonal asymmetries in both H^+ and He^+ are also correspondingly less pronounced. In particular, the broad deep trough in H^+ observed at the α = +32° position is not reproduced at α = -12.5°, even though a significant narrow trough does occur near 70° in the winter hemisphere. Because of the lack of a pronounced seasonal shift at the α = -12.5° position, H^+ remains the dominant light ion at all latitudes, even in the winter hemisphere.

The Winter Bulge and Equatorial Trough in He^+

In order to further examine the pronounced seasonal variability in the distributions of He^+, we now examine the evidence of the equatorial trough in He^+ as well as the winter bulge in He^+, both of which are observed to be parameters which exhibit pronounced variation with longitude.

In Figure 9, He^+ profiles observed on May 26 and 28 exhibit the distinct differences observed in the He^+ distributions at the contrasting longitudes of 134° and -51°, respectively. In general, the features of the latitudinal variation in He^+ are reproduced at both longitude positions. These features include a broad seasonal asymmetry in which the winter hemisphere concentrations of He^+ are as much as a factor of 5 greater than the concentrations observed at comparable latitudes in the summer hemisphere. Superimposed upon this seasonal asymmetry is a broad equatorial trough in He^+, marked by relative enhancements in the ion concentration near 30° latitude in both the summer and winter hemispheres. The character of both of these features changes noticeably with longitude. At the extreme seasonal position, -51° lg., $\alpha = 32°$, the winter asymmetry or bulge in He^+ becomes most pronounced, whereas at 134° lg., $\alpha = 10°$, the solar-geomagnetic seasonal orientation is reduced, as is the seasonal asymmetry in the He^+ profile. Similarly, the equatorial trough shows a distinct variation with longitude, with the trough widening significantly at the position of maximum α.

The seasonal variation in the He^+ distribution is examined in Figure 10, which includes data observed on May 27 and December 12, 1968. In the left panel, a comparison of profiles obtained at essentially the same longitude (-95°, -93°) exhibit a course degree of similarity with regard to seasonal asymmetry, although noticeable differences are observed. In the right hand panel, however, profiles observed at widely <u>different</u> longitudes (+75°, -75°) but at <u>identical</u> α positions (+33°) exhibit a remarkable degree of symmetry with respect to the opposing seasonal conditions. Note that the winter hemisphere maximum concentration level, the breadth of the winter bulge, and the general features of the latitudinal profile are well reproduced between May and December.

DISCUSSION

General Aspects of the Longitudinal Variation

Although it has been fairly well established that the geomagnetic field plays an important part in regulating the distribution of upper atmosphere ionization, the present data provide the first detailed evidence of the results of such effects upon the components of the ion composition. Early results from the plasma probe experiment on Ariel-1 provided tentative evidence of the geomagnetic control, although this feature could not be evaluated in detail [Bowen et al., 1960]. A study of topside sounder data by Chandra and Rangaswamy [1967] showed that certain latitudinal variations observed in N_e near 1000 km. could be explained on the basis of the latitudinal variation in the magnetic dip angle and the solar zenith angle. While this conclusion appears to be closely associated with the present results, the previous study did not include any information on the topside ion composition.

More recently, studies of the ion composition results from Explorer-32 by Brinton et al., [1969] has shown that the altitude of the O^+-H^+ transition level changes markedly between positions of widely different longitude. The Explorer-32 results have also revealed pronounced seasonal variations in N^+ and O^+, which when averaged, correlate with variations in solar zenith angle [Brinton et al., 1969]. This work, which leads directly to the present study, unfortunately lacked the continuous data coverage required for the more thorough, orbit to orbit evaluation obtained with the present results.

It is emphasized that in earlier studies the resolution and techniques available have often seriously limited attempts at identifying long term variations in the topside ion composition, including seasonal and local time changes. Because of the complex orbital motions usually involved, it is frequently necessary to average results obtained in data samples which are generally rather broad in terms of either altitude, latitude, longitude, or local time variations, or combinations of these parameters. Only by obtaining orbit to orbit data continuity is it readily possible to examine the longitudinal variation, and subsequently better isolate and possibly identify the importance of altitude and magnetic activity effects.

Another point to be emphasized is that the observed repetitive longitudinal variations are not associated with magnetic storms, and also are not attributed to large scale geomagnetic field distortions, such as the well known South Atlantic Anomaly. Specifically, the patterns of the longitudinal variations are observed to repeat at different seasons (with predictable seasonal reversals). Such results, which necessarily include an arbitrary sampling of magnetic conditions and longitudes, provide evidence that the systematic longitudinal variation is associated with a fixed solar-geomagnetic relationship. Large-scale distortions of the geomagnetic field associated with pronounced storms and/or the anomaly may, however, be expected to provide additional, prominent variations in the ion distributions.

Mechanisms Associated with the Solar-Geomagnetic Seasonal Variations

Although a variety of distinct ionospheric features have been identified in the topside composition, including the wobble of the O^+/H^+ ratio, the latitudinal variation of the H^+/He^+ ratio, and the winter bulge and equatorial trough in He^+, it is doubtful that these features result from distinct or completely independent mechanisms. For example, it is clear that the latitudinal variation of the solar zenith angle must play an important part in determining the observed seasonal asymmetries in the ion composition. Nevertheless, these same results, if plotted in geodetic rather than dipole latitude, would of course, continue to exhibit the pronounced seasonal asymmetries at positions of contrasting longitude, even though the zenith angle relationships would be the same for both longitudes. Accordingly, it is quite apparent that simple solar seasonal factors alone are insufficient to describe the complex distributions of topside ionosphere, and that additional mechanisms are somehow interacting with the basic solar input so as to produce the observed anomalies.

The observed longitudinal variation in the O^+/H^+ ratio is indicative of the complexities suggested above. In particular, these results suggest that by some as yet undefined processes a large scale redistribution of ionization occurs, which is superimposed upon the normal seasonal variation, and which may significantly modify the ion chemistry in regions where significant redistribution takes place. A likely mechanism which may be associated with such a process is the mass redistribution of ionization through the effects of a neutral thermospheric wind. Such a wind, described by Kohl and King [1967], is capable of inducing an appreciable ion flow, the coupling by means of ion drag. The resultant ion flow, directed either upward or downward along magnetic field lines should result in enhanced seasonal asymmetries in the ion composition. This theory has been tested specifically by Brinton et al., [1969] using transition level data obtained from Explorer 32. The results of this study show that a neutral wind with a N-S horizontal velocity of 50 meters/second is capable of producing transition level altitude changes of as much as 400 km, between positions of contrasting longitude. Although this study did not include the possible effects of electromagnetic drifts, a recent calculation by Stubbe and Chandra [1970] has shown that a W-E electric field can match the effects of the N-S neutral wind in producing redistributions of F layer features, although in the absence of global results on the upper atmosphere electric fields, the appropriateness of the field mechanisms remains to be determined. It is, of course, quite likely that even during moderately quiet magnetic periods, electric field variations do occur, and that as a result, interactions between the neutral wind and electric field effects must exist.

As an added complication, mechanisms responsible for the depletion of the light ions H^+ and He^+ at mid to high latitudes may also be expected to interact in some fashion with the effects of neutral winds and electric fields. According to the concept of the polar wind model [Banks and Holzer, 1968] the escape of light ions will be induced not only across the poles but also toward mid latitudes in the range of the plasmapause. As shown by Mayr et al [1969] significant upward fluxes of protons would be required to explain the correlation observed between the mid latitude light ion trough and the plasmapause. Recent studies of Explorer 32 ion composition data have, in fact, revealed the presence of strong upward fluxes of H^+ and He^+, extending from higher latitudes toward the plasmapause [Brinton and Grebowsky, 1970]. Thus it is possible that within the same group of midlatitude field lines, there may co-exist a number of competing processes which may interact so as to either amplify or cancel the fundamental ionization changes induced by normal seasonal variations.

The observed complex seasonal variations may also in part be attributed to chemical changes resulting from the redistribution of ionization. For example, if quantities of O^+ are shifted to lower altitudes through the action of downward directed field aligned neutral winds, an ion sink may be formed as a result of the enhanced recombination of O^+ and H at the lower altitude. Similarly, imbalances brought about in the H^+ and He^+ chemistry produced as a result of the upward fluxes at the plasmapause and beyond, may in turn alter the expected latitudinal variations in these ions, as well as in the heavier ions O^+ and N^+.

The neutral wind mechanism also appears to be a likely prospect for explaining the pronounced seasonal asymmetry or winter-time bulge in He^+. Reber et al., [1970] have observed an order of magnitude difference in the ambient concentrations of He between the 60° latitude position in the winter and summer hemispheres. The observed helium distribution asymmetry has been accounted for by coupling the momentum and continuity equations for helium with a model for the thermospheric wind field. Following this, it is evident that the present results of the winter bulge in He^+ may be explained simply on the basis of the increased ionization which would follow directly from the winter bulge in neutral helium. Again, however, the implication for possible seasonal imbalances resulting in the interrelated chemistry involving helium, oxygen, and nitrogen remains to be determined. As discussed earlier, the additional complexity imposed by the effect of strong upward fluxes of light ions toward the higher latitudes would appear to be significant in the investigation of the anomalous winter-time behavior of helium.

Toward low latitudes and the equator, the seasonal variations of ion distributions also appear to be relatively complex. The broad, deep equatorial trough in He^+ appears as a distinct and persistent feature of the topside ionosphere, observed at a wide range of local times. Chandra et al., [1970] have observed a similar feature in the nighttime ion data obtained with the OGO-4 retarding potential analyzer, and have suggested that the He^+ depletion might be explained by a simultaneous increase in O^+, and/or N^+, accompanied by the appropriate charge transfer reaction. The present results, however, as well as preliminary data obtained at other local times, do not consistently show a simultaneous and pronouncec change in either O^+ or N^+ occurring with the He^+ trough, and thus this interesting question involving the ion chemistry remains unanswered. An alternate mechanism for producing the He^+ anomaly consists of the combined effects of a latitudinal increase in the T_e/T_i ratio coupled with a hemispheric neutral wind circulation [Mayr et al., 1970]. In any event, the strong solar-geomagnetic seasonal variation of the equatorial He^+ trough suggests that both field aligned ionization and transport processes are important for determining the distribution of He^+.

The solar-geomagnetic seasonal variations in the light ions H^+ and He^+ reveal for the first time that these ions are not simply distributed above the earth in fixed concentric layers. The complexity of both the latitudinal and longitudinal variations in the distributions of the light ions makes an evaluation of the relative importance of these two ions a complicated process. Similarly, it would appear that past attempts to ascertain the solar cycle variation in H^+ and He^+ may not have been conclusive, due to the method of sampling and comparison of results obtained at different times and locations. In particular, the present evidence that $\underline{He^+ \text{ may exceed } H^+}$ by as much as a factor of 5-10 over a very narrow latitude range in the extreme winter hemisphere, while at the same time H^+ may exceed He^+ by as much as a factor of 50:1 in the summer hemisphere, raises some doubt relative to the results of some earlier studies of H^+/He^+, which were generally dependent upon data averaged with respect to time and position. The present results, supported by earlier OGO-4 data on H^+/He^+ at other local times [Taylor et al., 1969b] indicate that a dominant helium ion belt did not form near the maximum of solar cycle 20, and that transport and/or chemical processes can dominate over solar cycle effects in determining the localized prominence of He^+ with respect to H^+.

SUMMARY

Results of topside ion composition measurements obtained during 1968 from the polar orbiting OGO-4 satellite reveal that:

(1) The pole-to-pole latitudinal distributions of the primary topside ions O^+, H^+, N^+, and He^+ exhibit distinct and repetitive variations with respect to longitude. These variations appear as pronounced changes in the position and prominence of significant topside features which include the O^+-H^+ transition level, the H^+/He^+ ratio, the winter bulge in He^+, and the equatorial trough in He^+, and the high latitude depletion of H^+ and He^+.

(2) The trend of the longitudinal variation is such as to magnify the latitudinal asymmetries in composition which might be expected as a result of seasonal variations. Since the seasonal asymmetries are observed to be most enhanced at those longitudes for which the sun-earth-magnetic field geometry reaches extreme positions, the term "solar-geomagnetic season" has been introduced as a new concept.

(3) A comparison of daytime composition data obtained at the contrasting seasons of May and December shows that the solar-geomagnetic seasonal variation persists at different local times and seasons, with latitudinal asymmetries which might be expected from the seasonal variations involved.

(4) The evidence of the longitudinal variation obtained during periods of moderately quiet geomagnetic activity (Kp $\lesssim$ 2) as well as additional data obtained for a variety of magnetic conditions and locations, indicates that the solar-geomagnetic seasonal variation is a permanent feature of the topside ionosphere, and is not dependent upon anomalous conditions.

(5) As a result of the extreme variations in the local concentrations and in the latitudinal position of prominent features observed with respect to longitude, it appears that, to be rigorous, future correlative studies as well as the development of ionospheric models must account for the longitudinal variations observed.

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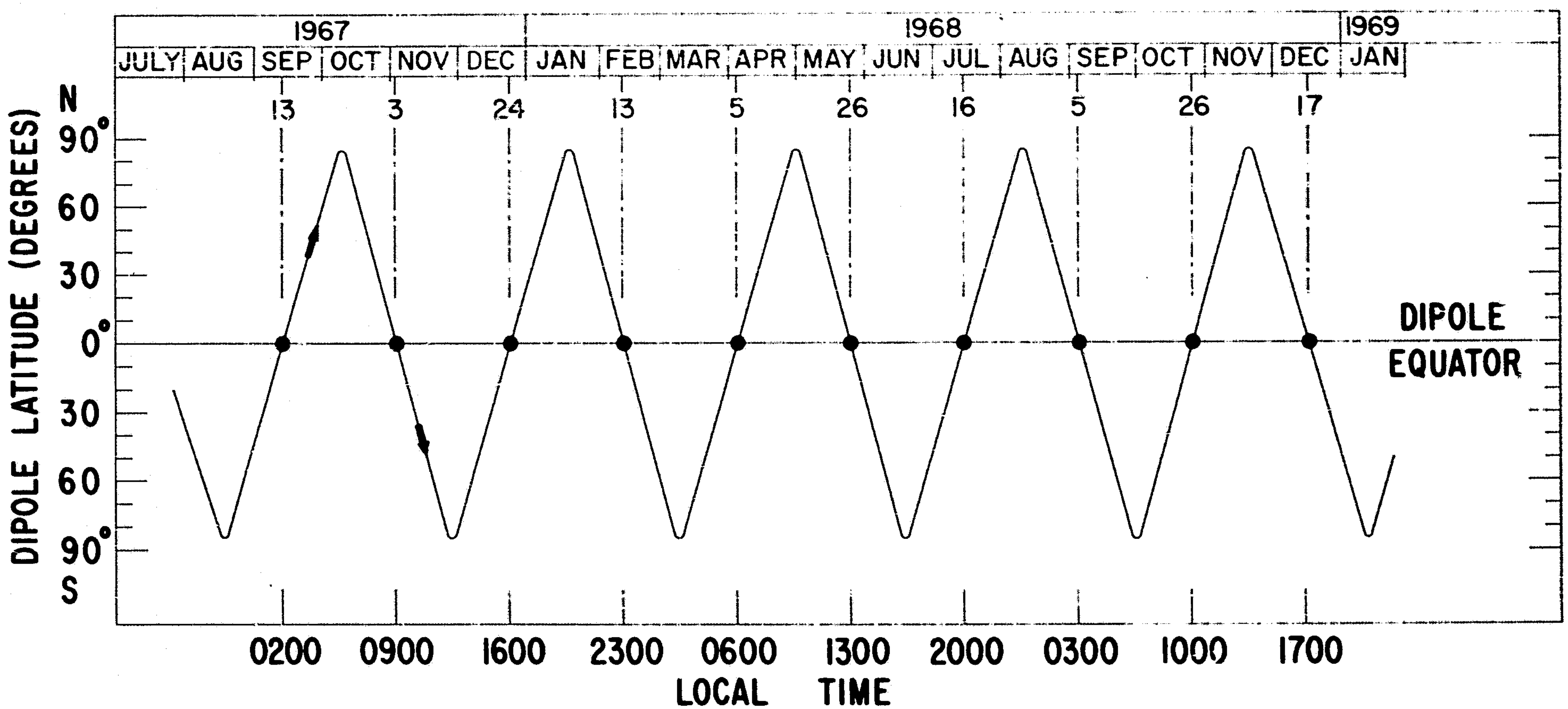

Figure 1. Time history of the variation of the apogee of OGO-4 with respect to dipole latitude and local time. The approximate position of apogee-dipole equator crossings is indicated by the black dots.

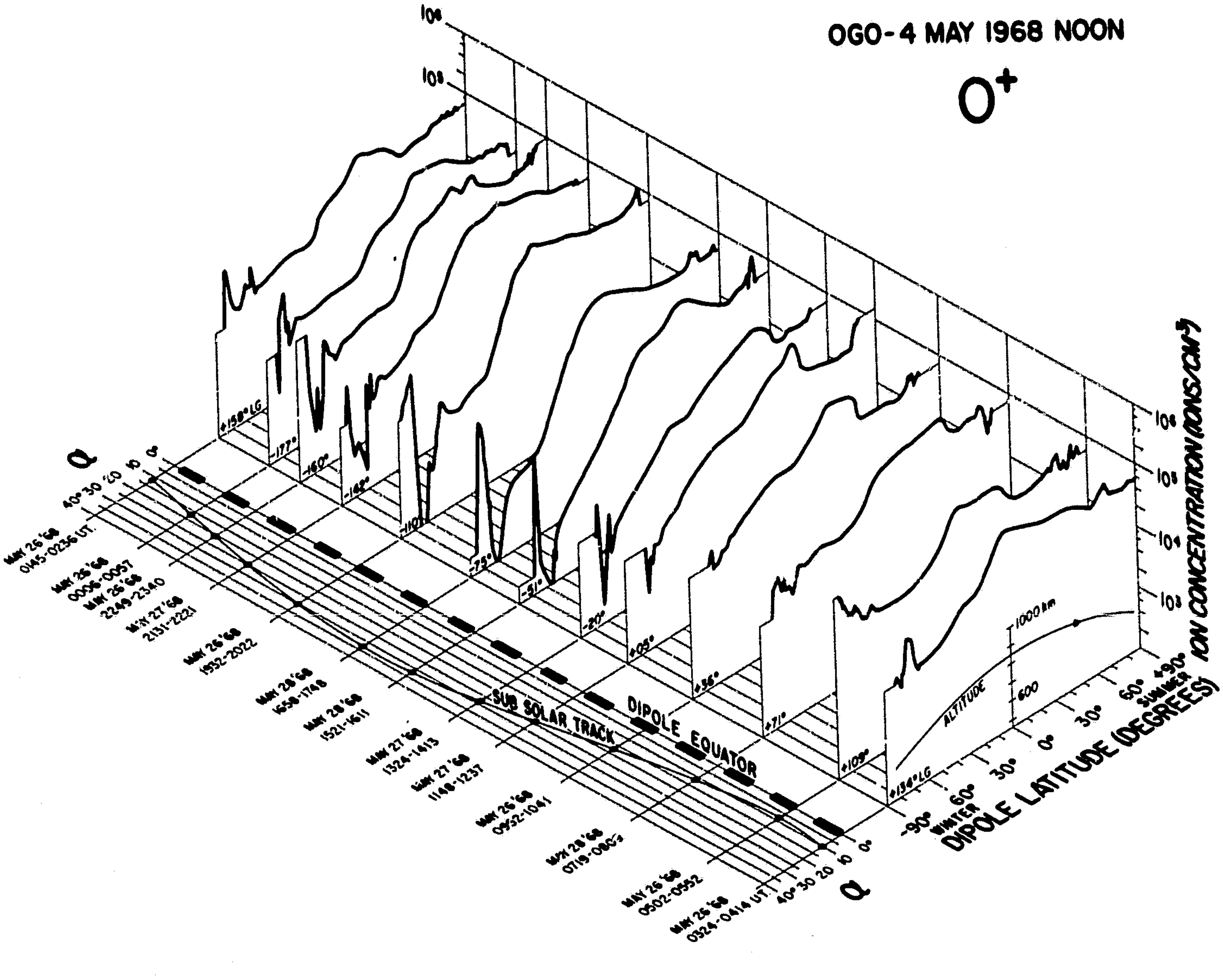
OGO-4 MAY 1968 NOON
O^+
ION CONCENTRATION (IONS/CM³)
DIPOLE LATITUDE (DEGREES)
SUB SOLAR TRACK
DIPOLE EQUATOR
ALTITUDE
WINTER
SUMMER

Figure 2 (a)

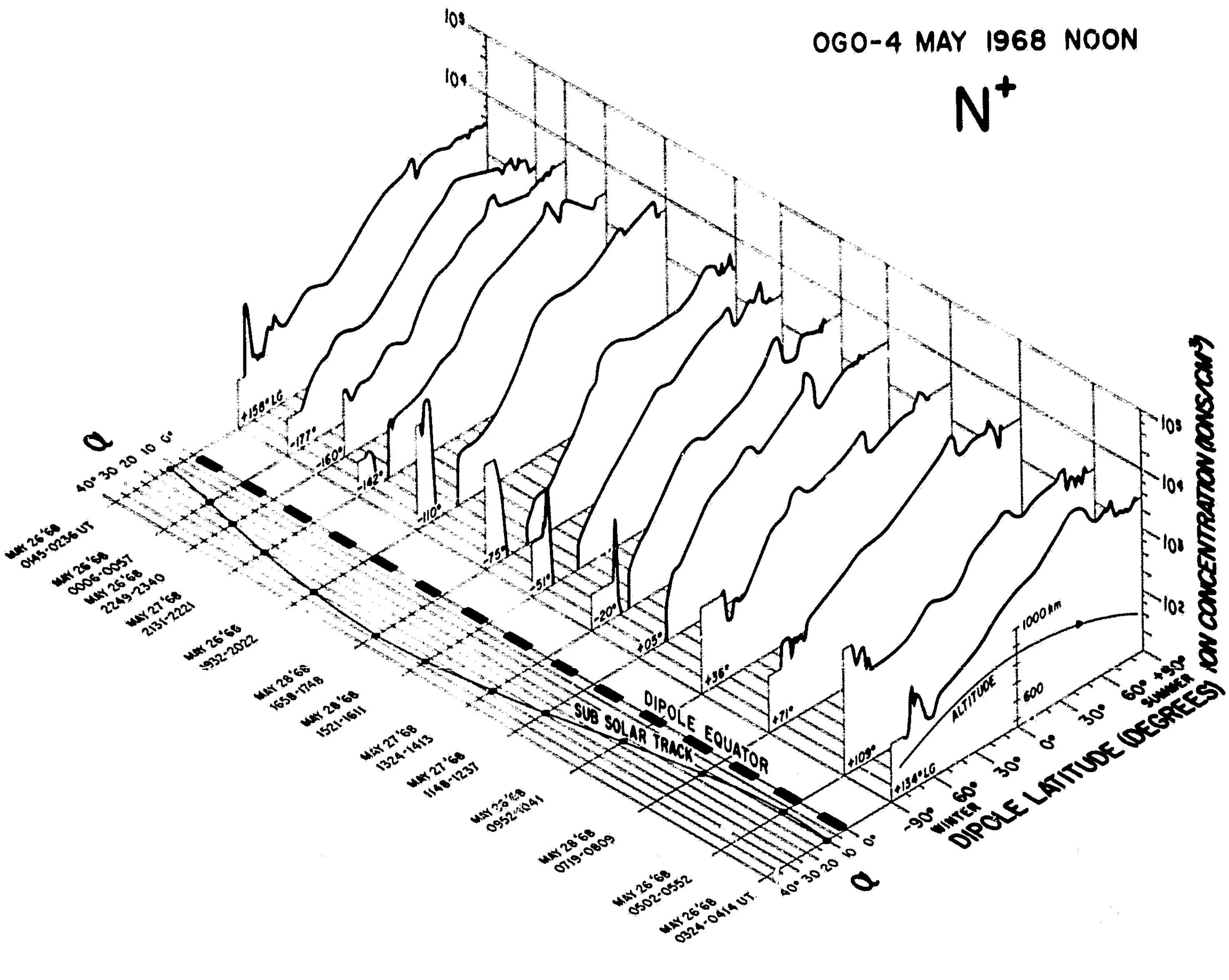
OGO-4 MAY 1968 NOON
N^+
ION CONCENTRATION (IONS/CM³)
DIPOLE LATITUDE (DEGREES)
DIPOLE EQUATOR
SUB SOLAR TRACK
ALTITUDE
1000 km
600
WINTER
SUMMER
α

Figure 2 (b)

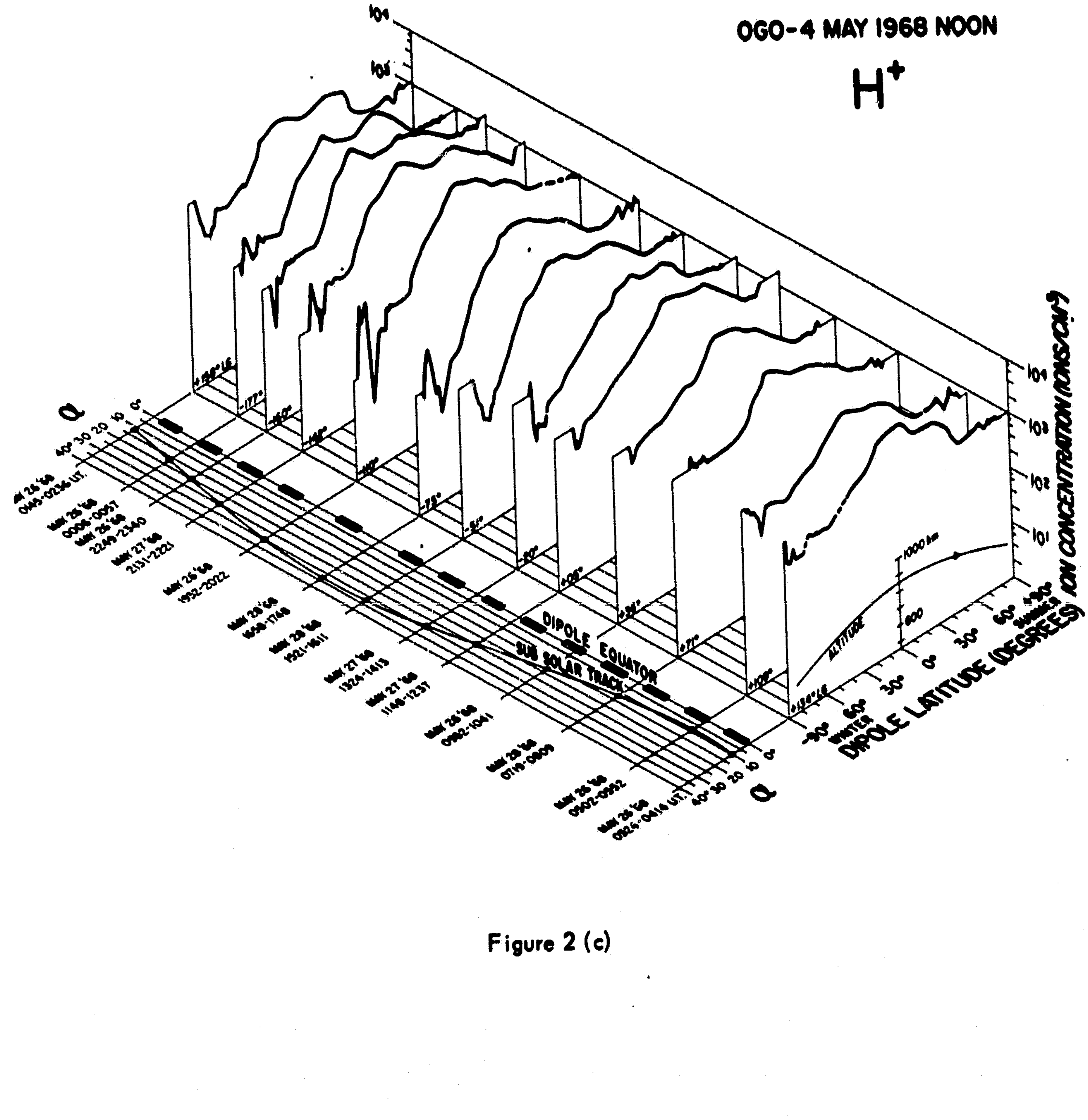
OGO-4 MAY 1968 NOON
H+
ION CONCENTRATION (IONS/CM³)
DIPOLE LATITUDE (DEGREES)
DIPOLE EQUATOR
SUB SOLAR TRACK
ALTITUDE
α

Figure 2 (c)

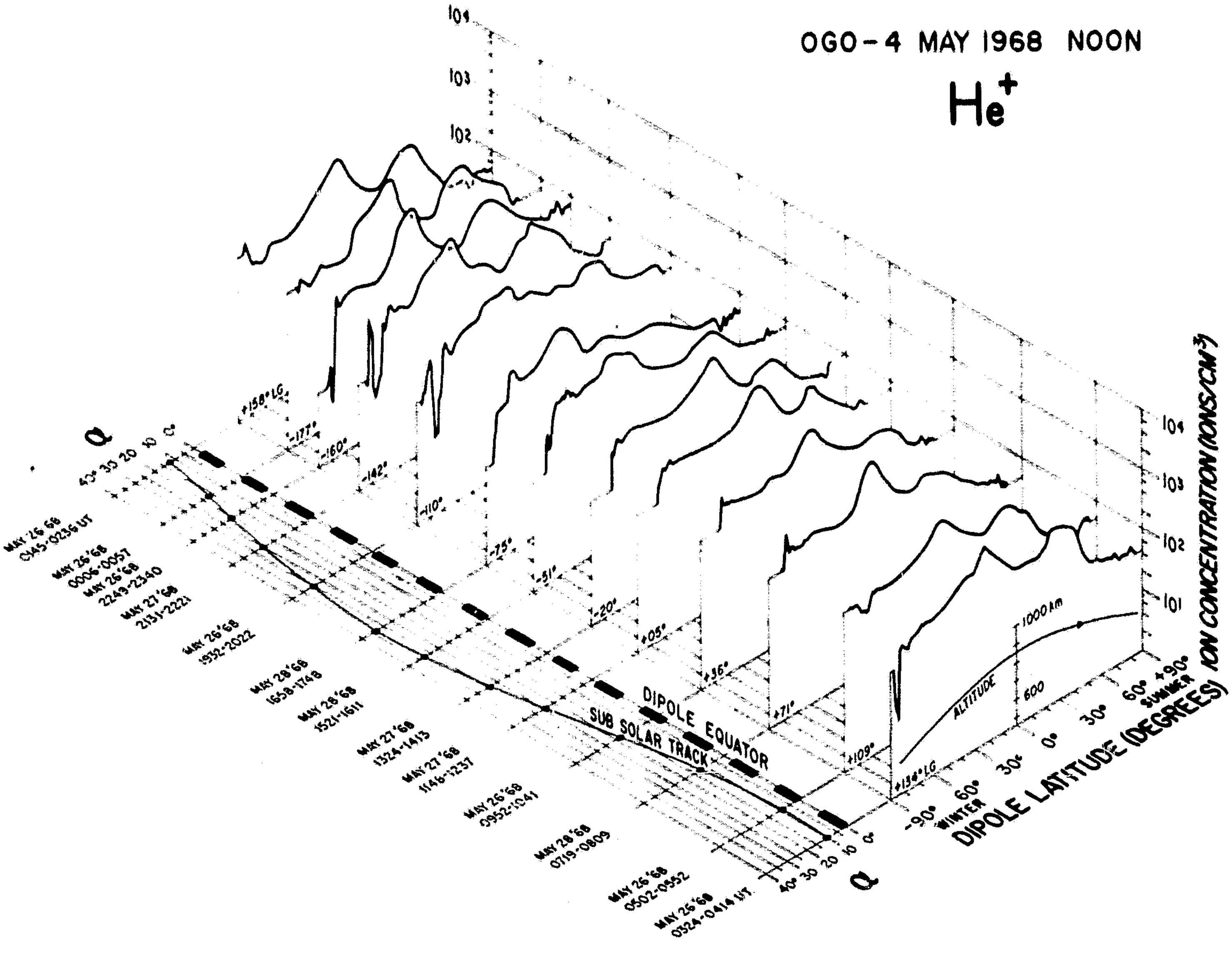

Figure 2(a–d). Families of pole-to-pole ion distributions which reveal the pronounced longitudinal variation in the topside ions O^+, N^+, and He^+ respectively, plotted against dipole latitude, longitude and α. The angle α is defined as the angle between the earth-sun line and the plane at the dipole equator and is measured as the satellite crosses the dipole equator. This data set was obtained in the interval May 26-28, 1968 near noon local time. The altitude versus dipole latitude plot shown on the first profile is representative of conditions for the remainder of the profiles, the maximum altitude variation at a given latitude being of the order of 100 km between any two profiles.

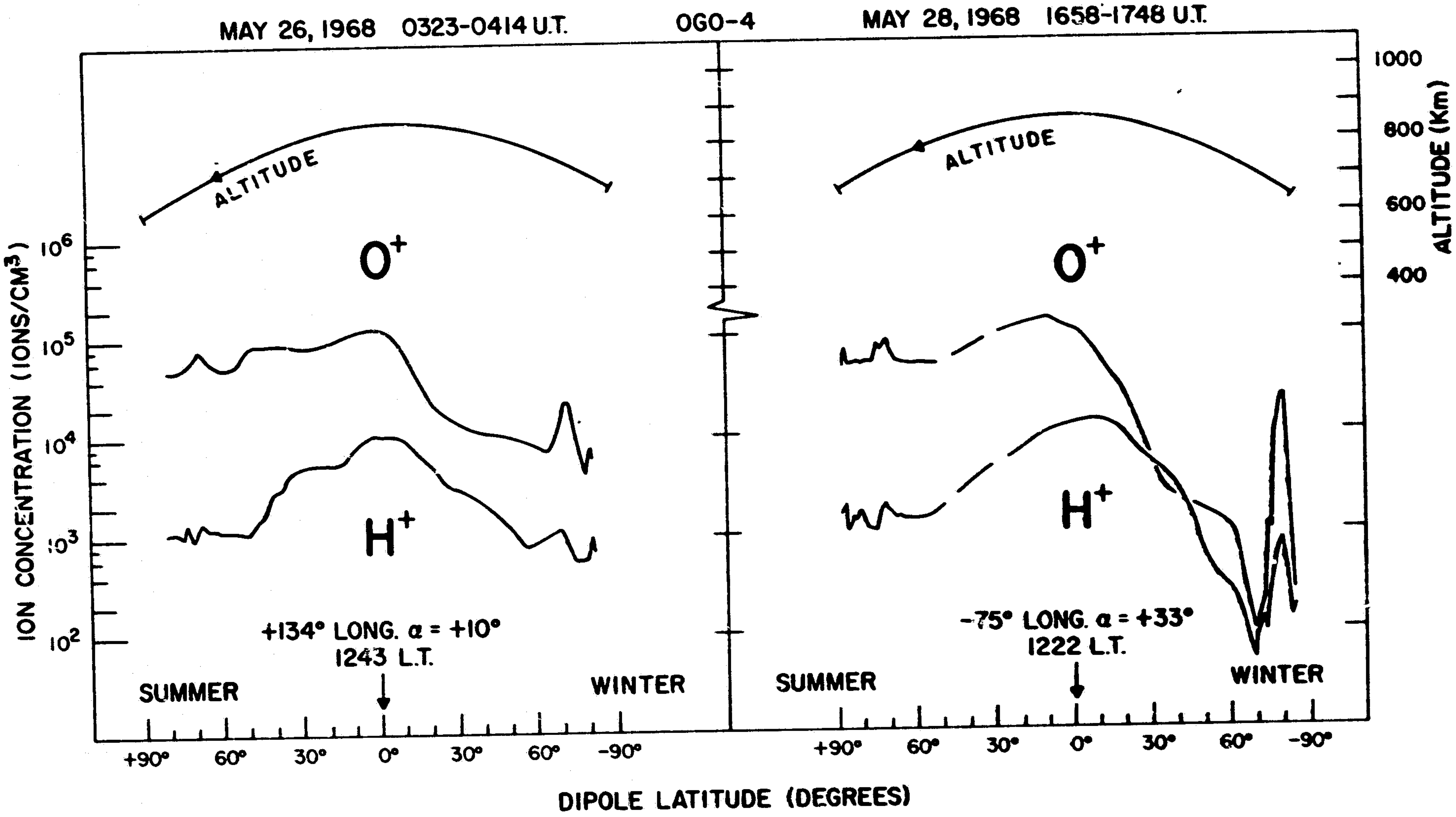

Figure 3. A comparison of O^+ and H^+ profiles obtained at positions of contrasting longitude on May 26 and 28, 1968.

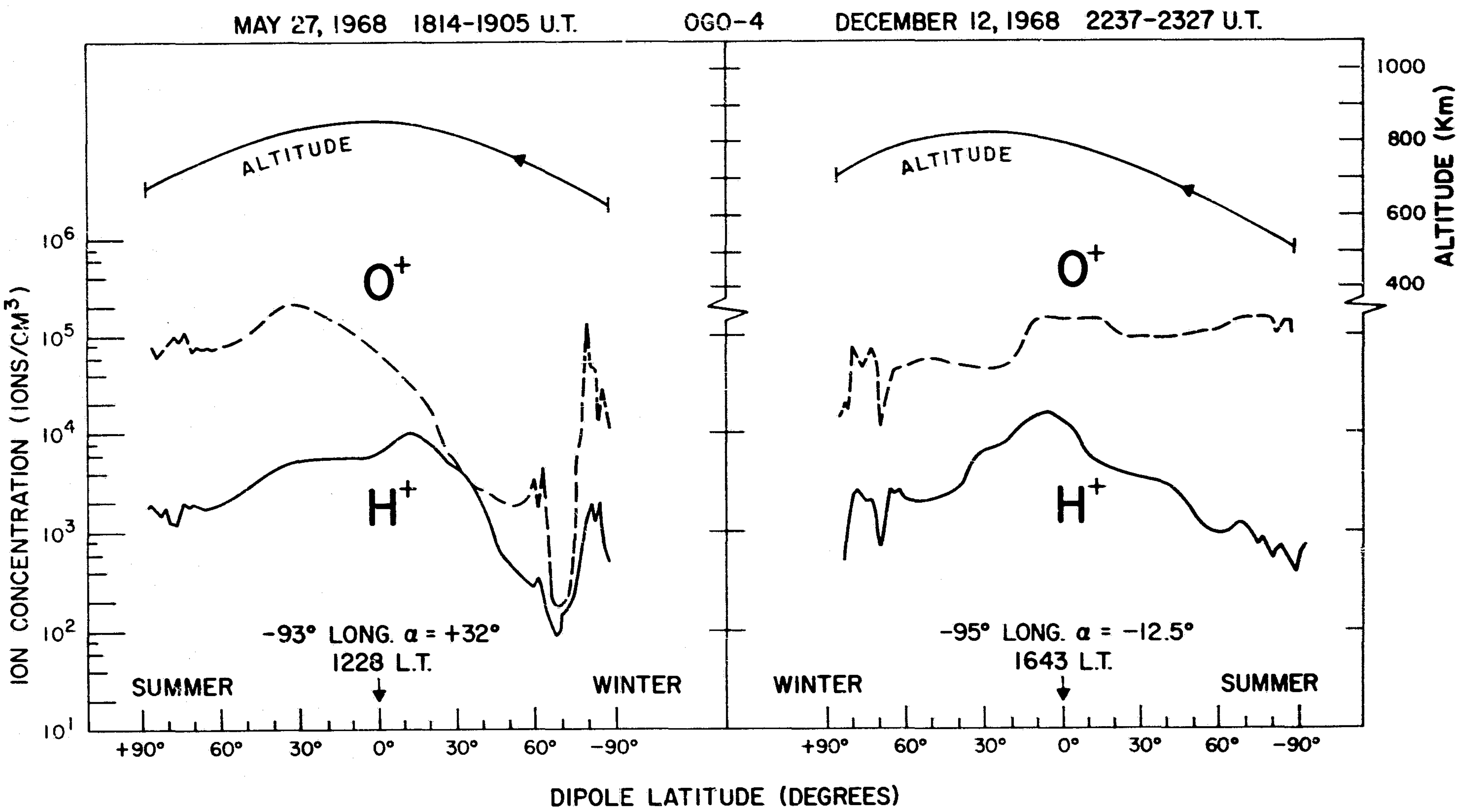

Figure 4. A comparison of O^+ and H^+ profiles obtained at essentially the same longitudinal position, on May 27 and December 12, 1968. Note that while the longitudes are nearly identical, the α for solar-geomagnetic seasonal position is distinctly different for these two sets of profiles. The left-hand panel is indicative of true solar-geomagnetic summer-winter conditions, while the right-hand panel gives results at a position of a much closer to the condition to solar-geomagnetic equinox, even for the month of December.

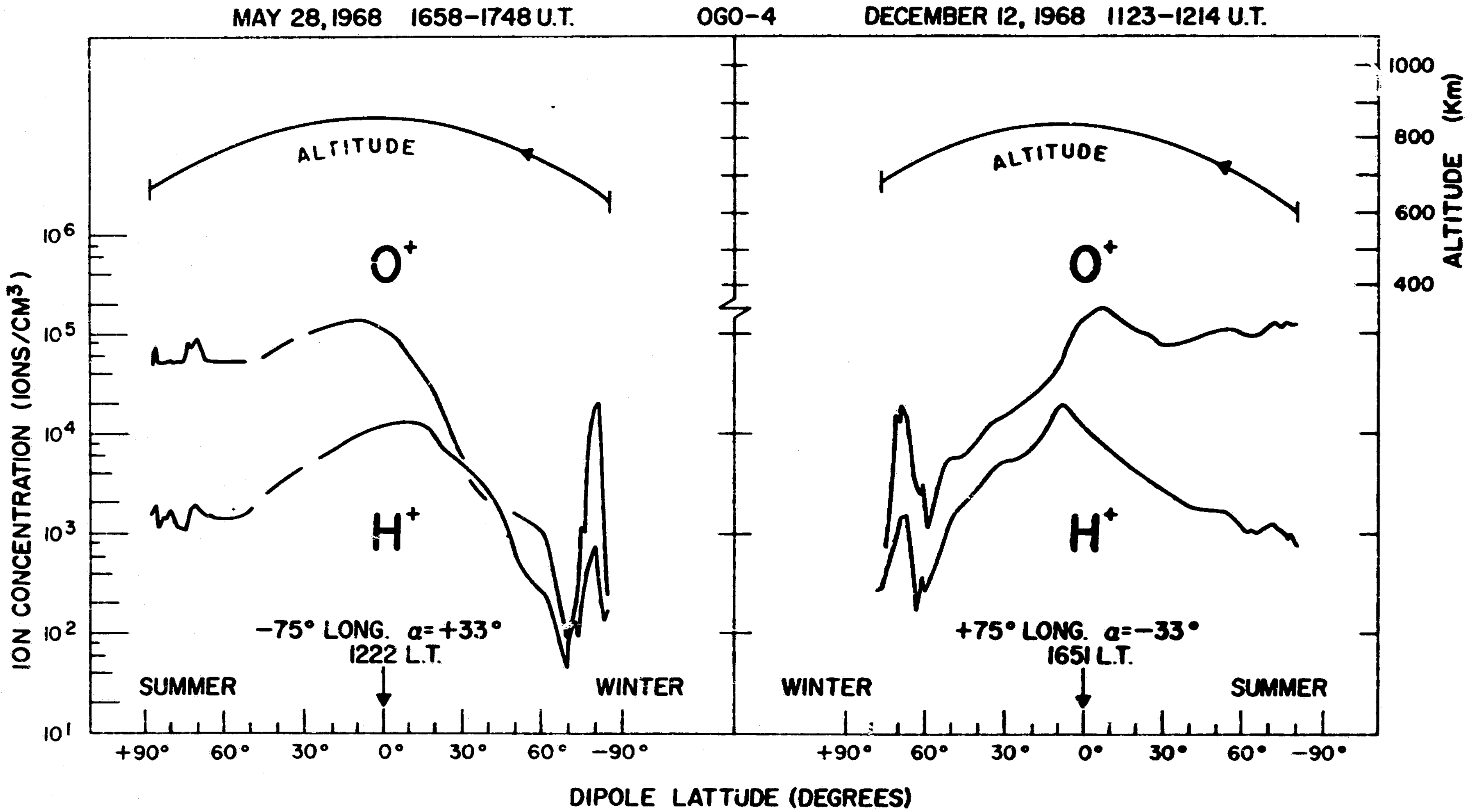

Figure 5. A comparison of O^+ and H^+ profiles at positions of contrasting longitudes, observed on May 28 and December 12, 1968. Note that while the longitudes are quite different, the α amplitudes are identical, indicating that the solar-geomagnetic season is nearly the same for both sets of profiles, even though the solar seasons are widely different.

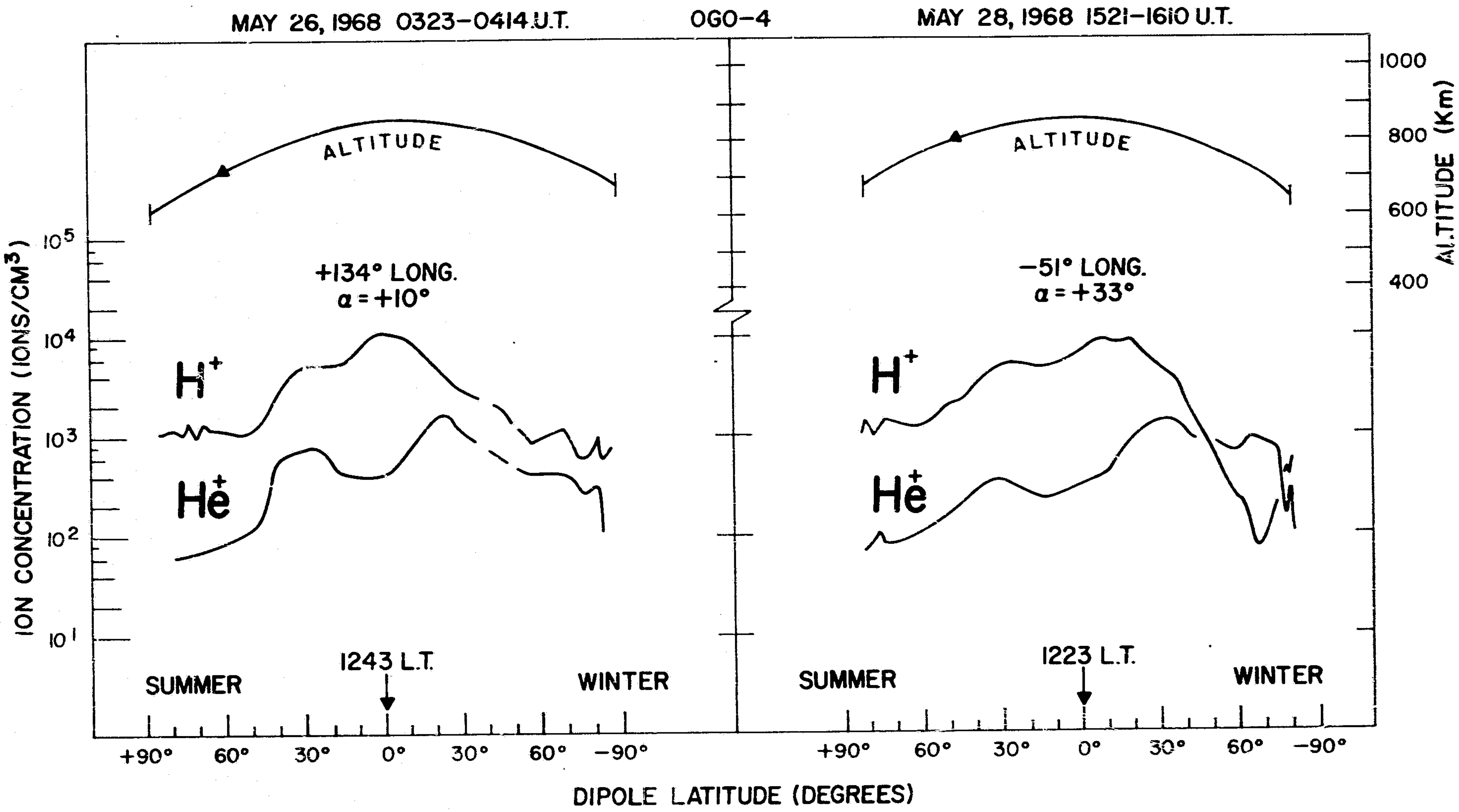

Figure 6. A comparison of H^+ and He^+ profiles obtained at contrasting longitude positions on May 26 and 28, 1968.

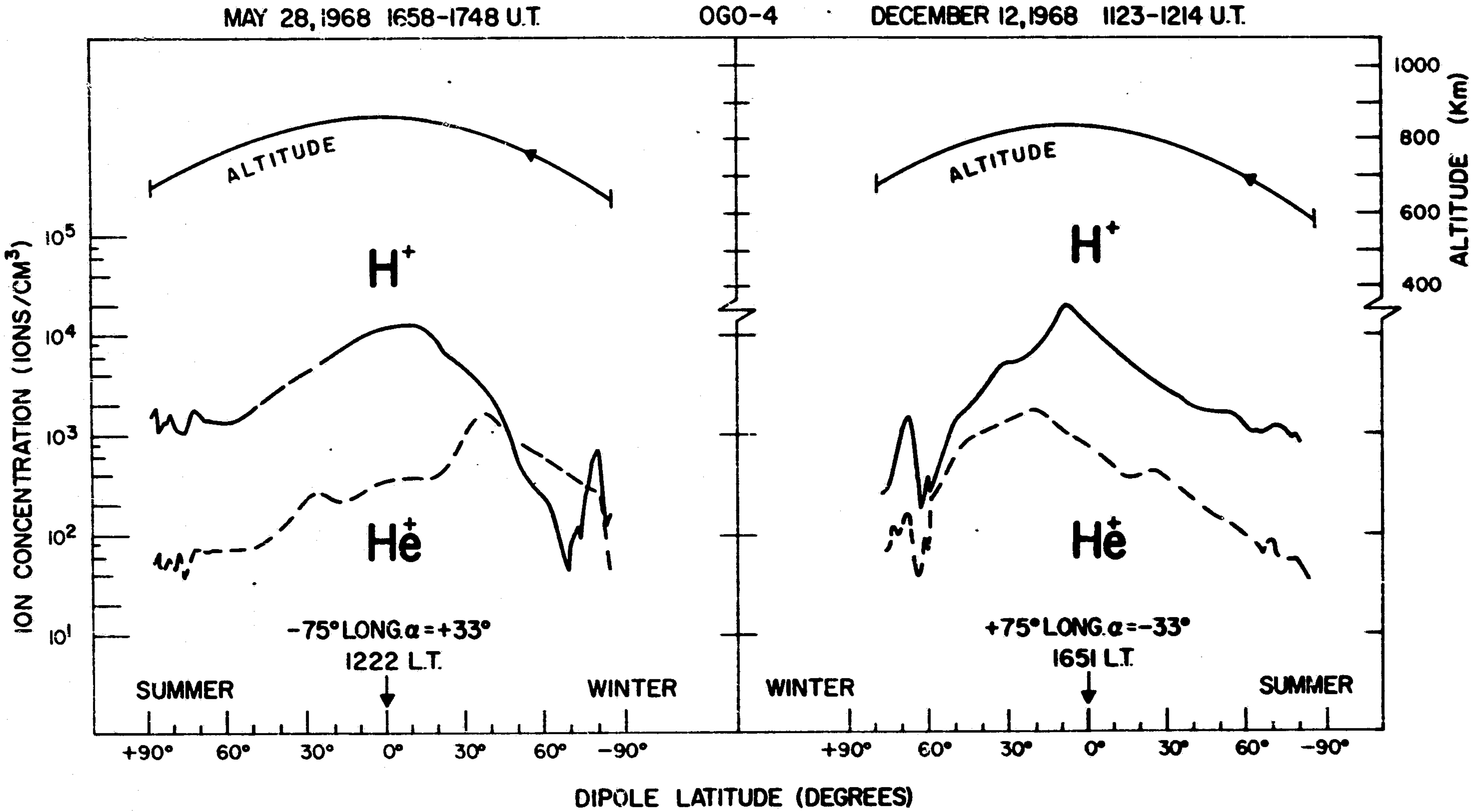

Figure 7. A comparison of H^+ and He^+ profiles obtained at contrasting longitudes on May 28 and December 12, 1968. Note that while the longitudes are quite different, the α amplitudes are identical, indicating similar solar-geomagnetic seasonal conditions.

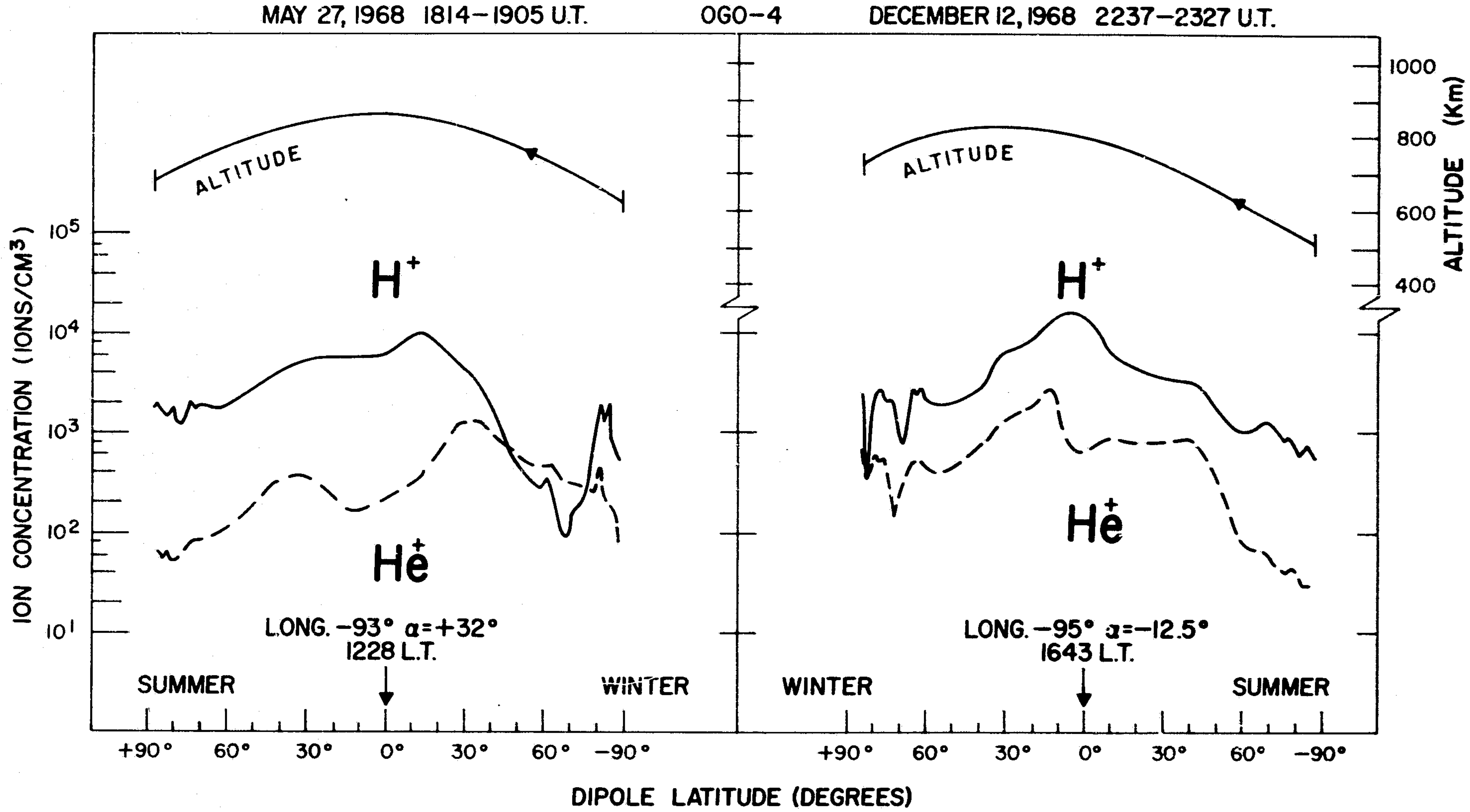

Figure 8. A comparison of H^+ and He^+ profiles obtained at nearly identical longitudes on May 27 and December 12, 1968. Note that while the longitudes are nearly identical, the α amplitudes are widely different, with the right-hand panel being indicative of conditions closer to solar-geomagnetic equinox than to winter. Note the similarity in the behavior of H^+ and He^+ observed on December 12 in this figure with the data shown from May 26 in the left-hand panel of Figure 7 (the α amplitudes for these two sets of profiles are nearly the same).

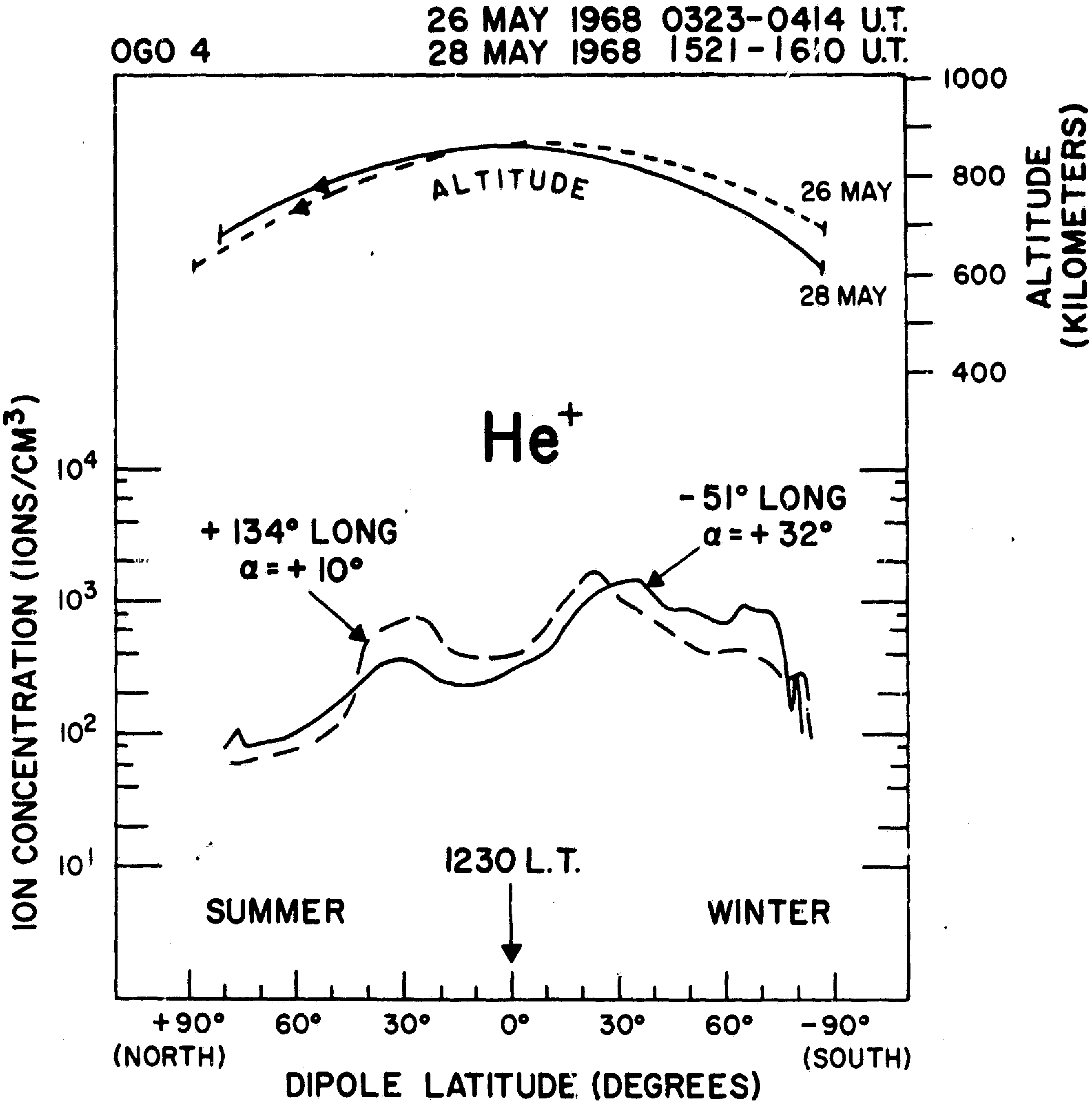

Figure 9. A comparison of He^+ profiles observed at contrasting longitudes on May 26 and 28, 1968. Note that the relative amplitude of the winter time He^+ bulge, as well as the general characteristics of the equatorial He^+ trough are noticeably different at the contrasting longitude positions.

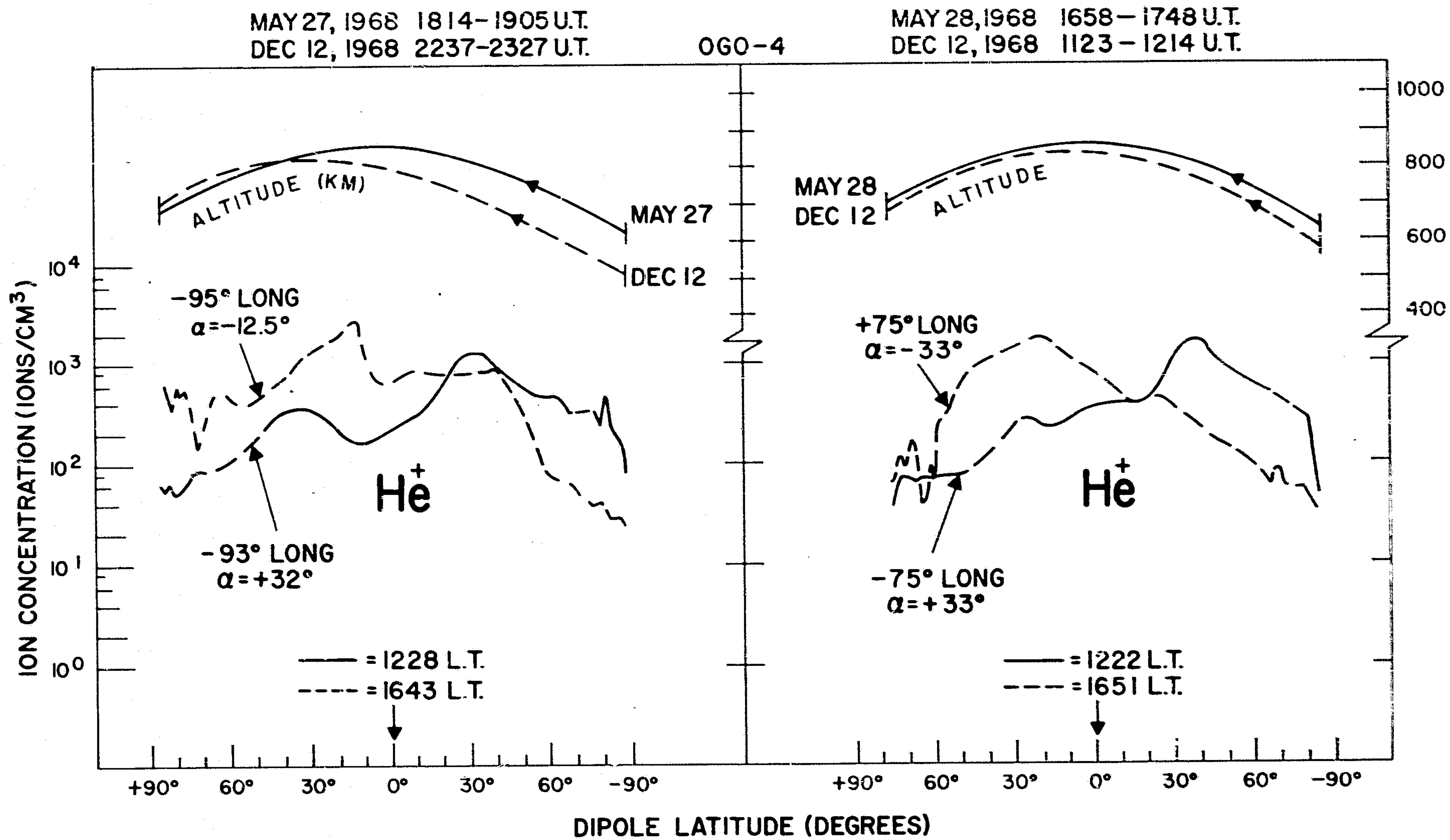

Figure 10. A comparison of He^+ profiles obtained in May and December, 1968. In the left-hand panel, profiles obtained at nearly identical longitudes but widely different α positions show limited similarities in the seasonal reversal of the latitudinal distribution. In the right-hand panel, profiles obtained at widely different longitudes, but identical α amplitudes show a pronounced similarity in the seasonal reversals.