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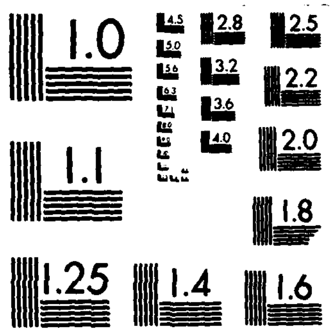

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Ion Composition Measurements of the Disturbed and Quiet D-Region in 1980-1981

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21 November 1984

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IONOSPHERIC PHYSICS DIVISION PROJECT 2310
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MA 01731

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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Mass-spectrometric data were obtained from rocket-borne instruments flown from Poker Flat, Alaska, during October 1980 and 1981 under disturbed and quiet conditions, respectively. The positive ion spectra for both events appear to be compatible with our current understanding of the D-region. The instrument configuration (cone front) yielded poor negative ion currents. Much more work is needed to develop a D-region mass spectrometer which accurately observes in-situ negative ions. This need is underscored by the fact that only light negative ions, possibly mostly contaminants, were present near 80 km. Ions two to three times heavier were obtained in earlier flights with a blunt front end configuration. Nitric oxide profiles derived for both cases were within the range expected. The 1980 flight, under disturbed conditions, yielded higher concentrations than did the 1981 flight.

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Preface

The late Dr. Rocco S. Narcisi conceived a program to conduct measurements of the D-region during a solar proton event (SPE). Solar proton events are infrequent but last for several days once they occur. Hence, instrumented rockets were first set up at Poker Flat, Alaska, and the experimenters based in the Boston area were to go to Alaska and launch the rockets upon receiving word that an event had started or was very surely imminent. Since D-region changes from day-to-night were of interest, winter months were inappropriate. Before winter's arrival, we decided to launch a rocket in late October 1980 during a D-region disturbance associated with a geomagnetic storm as a test. A second rocket was fired to measure the energetic electron flux and electron concentration profile. Over Columbus Day weekend in October 1981, an SPE did occur and personnel arrived at Poker Flat when the event was getting weak. (The holiday weekend probably contributed as much as a 24-hour delay in getting personnel to Alaska.) Since forecasters were strongly of the opinion that a second and stronger SPE was imminent, it was decided not to launch into the current SPE. Another event did not materialize and near the end of the month, with winter (dark days) approaching, a single rocket was launched into the quiet D-region to make background measurements. Although measurements were made successfully from all rockets (3) launched in this program, the approach of solar minimum and the exigency of other programs forced the termination of this field program. This report primarily summarizes the mass-spectrometric observations made in this program. (Gerdien condenser data and retarding potential analyzer results have not yet been reduced.) This report is also a tribute to the late Dr. Rocco S. Narcisi.

Contents

Illustrations

Ion Composition Measurements of the Disturbed and Quiet D-Region in 1980-1981

1. INTRODUCTION TO THE 1980 EVENT

On 22 October 1980, two rockets were launched from Poker Flat, Alaska, (65.1°N, 147.5°W) during a significant geomagnetic disturbance which produced a strong auroral absorption event. The first rocket, a Paiute Tomahawk, (A 10.901-1) was launched at 1031 Alaska Standard Time (AST) or 2031 UT. At 151.5 sec after launch, the rocket reached apogee, 88.5 km. The solar zenith angle during the flight was 77.2°. The rocket payload consisted of a quadrupole mass spectrometer, pumped with a liquid helium, cooled cryopump for the measurement of positive and negative ions, a Gerdien condenser for the determination of positive and negative ion mobilities and total ion concentrations, plus a retarding potential analyzer (RPA) for the measurement of total positive ion and electron concentrations. Only the mass-spectrometric results from this rocket will be presented here. The payload was recovered in good condition and was reflown in 1981.

A second rocket, a Super Arcas, was launched 12-1/2 min after the first. The solar zenith angle was again 77° and the rocket's apogee was very similar to the previous rocket. This rocket bore an electron deposition scintillator for the measurement of the energetic electron flux plus impedance and D.C. probes for the determination of the electron concentration profile.

(Received for publication 5 November 1984)

2. POSITIVE ION RESULTS FROM ROCKET A10.901 - 1

The mass spectrometer flown in this program was developed with a special emphasis on the determination of the masses, quantities and altitude distributions of large cluster ions in the D-region. Hence, this instrument was labeled CIMS (Cluster Ion Mass Spectrometer). The details of the instrument have been fully discussed by Bailey et al. [1]

Ascent data obtained with Rocket A10. 901-1 is shown in Figure 1. The O_2^+ and NO^+ concentrations precipitiously decline with altitude below apogee at 88. 5 km. Based upon the limited ion concentrations available, if the NO^+/O_2^+ ratio increases above 87 km, as it appears, this same altitude is then the altitude of maximum ionization created by the precipitating electrons.

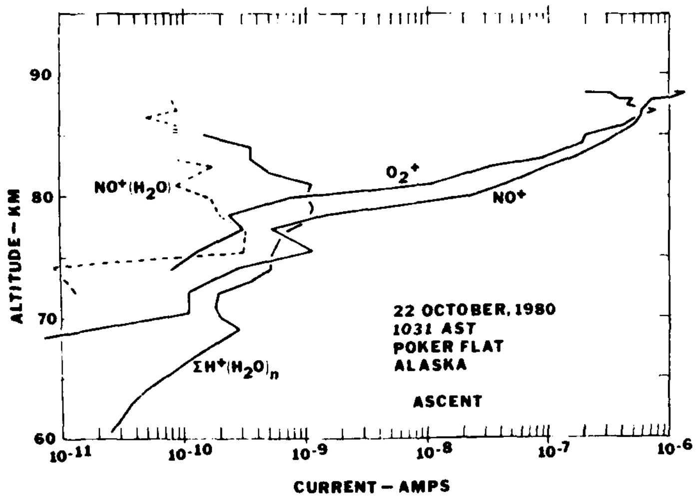

Figure 1. Positive Ion Data Measured on Rocket A10. 901-1 Ascent

Similar mass spectrometers were launched from Red Lake, Canada, into totality and post-totality for the 26 February 1979 solar eclipse. An electron precipitation event (or AZA-auroral zone absorption event) took place during the eclipse

1. Bailey, A., Narcisi, R., Wlodyka, L., Federico, G., and McKenna, E. (1982) Development of an Ion Mass Spectrometer and Sounding Rocket System for D-Region Cluster - Ion Measurements, AFGL-TR-82-002, AD A118752.

which gave results[2] comparable to those reported here. The peak ionization in the eclipse case occurred near 88 ± 2 km where O_2^+ ions attained a local peak concentration and the NO^+/O_2^+ ion ratio reached a local minimum.

It is well established[2,3] that a low NO^+/O_2^+ ratio in the D-region, that is, a high preponderance of O_2^+ ions, is the signature of a disturbed D-region. When energetic particles (protons, alpha particles, electrons) precipitate into the D-region, the principal ions formed are N_2^+ and O_2^+ since impact ionization cross sections are fairly independent of species and N_2 and O_2 are the principle neutral gases of the D-region. The N_2^+ ions are not observed since they quickly charge transfer with O_2 via the fast process, $N_2^+ + O_2 \rightarrow O_2^+ + N_2$. At D-region altitudes, NO^+ is produced by $O_2^+ + NO \rightarrow O_2 + NO^+$, and by the direct photoionization of NO by HLyα. This strong solar line penetrates into the D-region because its cross section for absorption (by O_2) is only 10^{-20} cm^{-2}.

The distributions of the oxonium ion, H_3O^+, and its hydrates, $H_3O^+ \cdot (H_2O)_n$, the hydronium ions, are depicted in Figure 2. The predominance of the ion $H_3O^+ \cdot H_2O$, labeled $H^+(H_2O)_2$ in the figure is a sure signature[3] of particle precipitation since it is well known[4] that this ion is the first hydronium ion originating from the precursor ion O_2^+. The cluster ion chemistry associated with the precursor ion NO^+ leads first to $H_3O^+ \cdot (H_2O)_2$ ions, also labeled $H_7O_3^+$ ions. The trend is for heavier ions to dominate with decreasing altitude. In modelling the ion composition at totality[5] for the 26 February 1979 eclipse, which included significant ionization down to at least 70 km, the hydronium ions $H_5O_2^+$, $H_7O_3^+$, $H_9O_4^+$ peaked at 82, 78 and 75-60 km (the lower limit of the model was 60 km) respectively. A roughly similar pattern is evident here. However, in the present case, ionization due to precipitating particles decreases rapidly with altitude as evidenced by the sharp drop-off in ion current with decreasing altitude below 85 km. Hence, data below about 75 km may well reflect only the quiet D-region.

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2. Narcisi, R., Bailey, A., Federico, G., and Wlodyka, L. (1983) Positive and negative ion composition measurements in the D- and E-regions during the 26 February 1979 solar eclipse, J. Atmos. Terr. Phys. 45:461-478.

3. Swider, W., and Narcisi, R.S. (1975) A study of the nighttime D-region during a PCA event, J. Geophys. Res. 80:655-664.

4. Ferguson, E.E. (1974) Laboratory measurements of ionospheric ion-molecules reaction rates, Rev. Geophys. Space Phys. 12:703-713.

5. Swider, W., and Narcisi, R.S. (1983) Steady-state model of the D-region during the February 1979 eclipse, J. Atmos. Terr. Phys. 45:493-498.

The rocket was gyro-stabilized so that both descent and ascent data could be taken in ram. The angle of attack, that is, the angle between the velocity vector and the rocket's major axis never exceeded 10°. The instrument was mounted on the top of the rocket with its pinhole entrance normal to the rocket's major axis. Little data was obtained on descent as a result of telemetry problems.

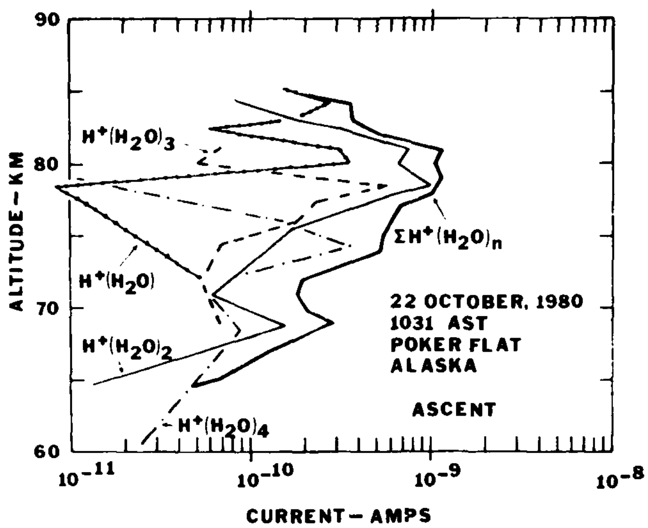

Figure 2. Positive Ion Data Measured on Rocket A10. 901-1 Descent

3. TOTAL POSITIVE ION CONCENTRATIONS

Negative ions are unimportant in the daytime D-region above about 70 km. Therefore, the total positive ion concentration above this height may be normalized to the electron concentration since the ionosphere is electrically neutral. As noted in Section 1, a Super Arcas rocket was launched 12-1/2 min after the rocket with the mass spectrometer. Electron concentrations derived from an rf-probe are shown for upleg and downleg portions of the flight in Figures 3 and 4, respectively. Electron concentrations are 9×10^4, 2.5×10^4 and 4.5×10^3 cm^{-3} for 88, 84 and 80 km on upleg, respectively and are 6×10^4, 2×10^4 and 6×10^3 cm^{-3} for these same heights on downleg. The rf-probe's operation is described in a Utah State University report.[6] Because of differences in launch times, the electron

6. Baker, K.D., Burt, D.A., Harris, R.D., Howlett, L.C., Jensen, L.L., Pendleton, W.R., Pound, E.F., and Albred, G.D. (1980) Rocket Measurements of D- and E-Region Parameters During the 26 February 1979 Total Solar Eclipse, Utah State University, Space Meas. Lab.

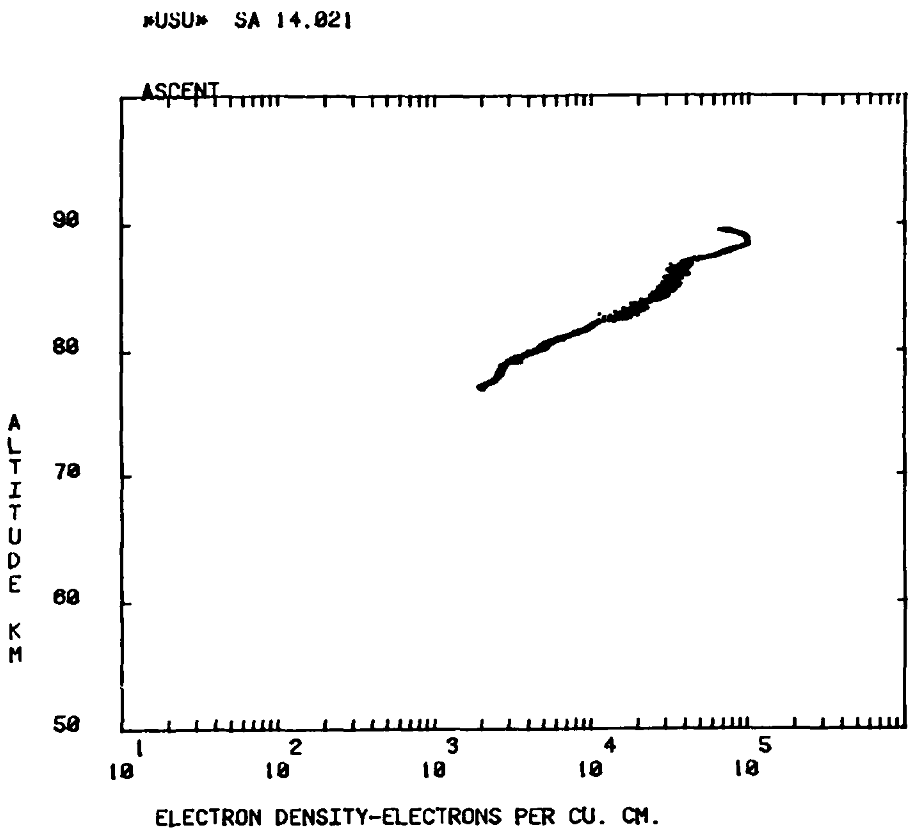

Figure 3. Electron Concentrations Derived From rf-probe Measurements on Rocket A14.021 Ascent

concentrations measured by this rocket are not necessarily identical to those appropriate for the Piute Tomahawk launched several minutes earlier. Nevertheless, we believe they are reasonably close.

The total ion concentration can be estimated from the mass-spectrometric data. In the 1979 post-eclipse flight,[2] positive ion current on ascent varied slowly from 2×10^{-6} A at 70 km to 8×10^{-6} A at 90 km. Total ion concentration measurements for the flight varied from about 10^4 to 4×10^4 cm^{-3}. Hence, the conversion factor was about 5×10^9 ions cm^{-3}/A. The instrument on the subject (1980) flight was twice as sensitive (see Table 5 of Bailey et al[1]) as the earlier flight, so the conversion factor should be about 10^{10} ions cm^{-3}/A. If this factor is applied to the data in Figure 1, the total ion concentrations at 88, 84 and 80 km are 1.4×10^5, 5.5×10^4 and 2.3×10^3 cm^{-3}. These results agree are within about a factor of two of the electron concentrations measured several minutes later. The higher value at 80 km from the rf-probe may relate to the fact that ion-neutral

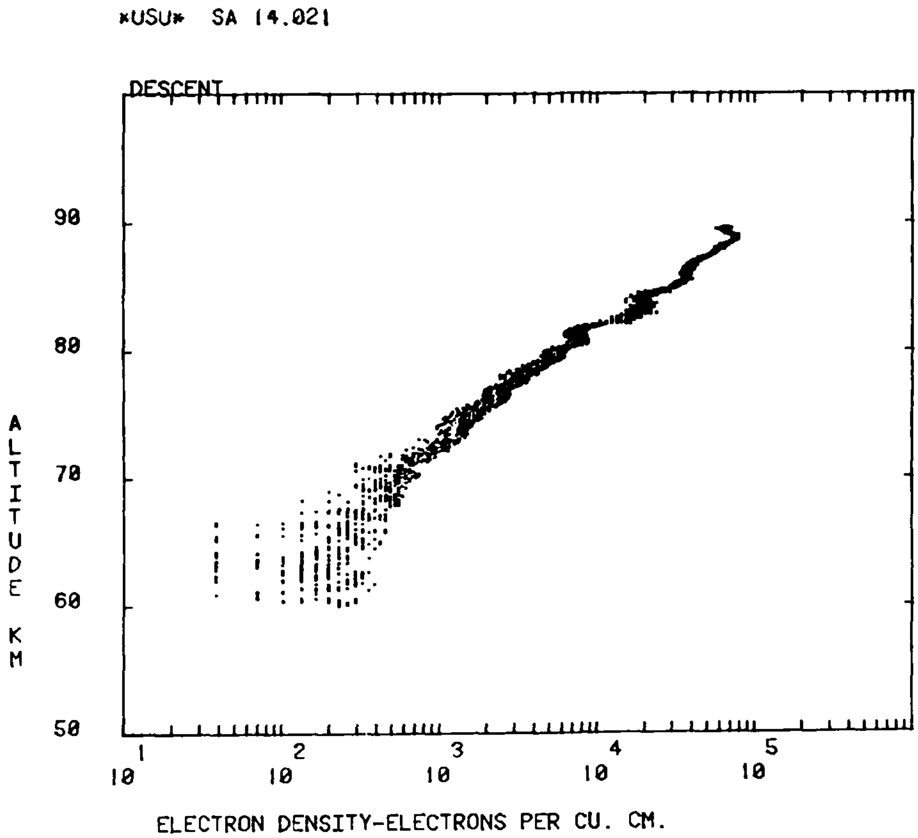

Figure 4. Electron Concentrations Derived From rf-probes Measurements on Rocket A14.021 Descent

collisions in probe current measurements as the rocket descends into the atmosphere. Hence we expect that the factor converting ion currents to concentrations must increase with decreasing altitude. On the other hand, the non-simultaneity of the flights alone could account for the differences between the two concentration profiles regardless of the fact that the rf-probe gives a more accurate concentration than our approximate conversion factor. In the post-eclipse flight,[2] a single conversion factor between total ion current and total ion concentration appeared to suffice for 90 to 70 km with a varying factor setting in below this height, the data petering out by 62 km.

The scintillator aboard the Super Arcas rocket showed small electron fluxes except for a few bursts that corresponded to the local electron concentration maxima observed just before and after apogee (Figures 3 and 4). Ground-based radars (Chatanika, NOAA's MST and HF) made some observations at the time of

11. CONCLUSIONS

As part of our SPE program, Paiute Tomahawk rockets were launched in October 1980 and 1981 from Poker Flat, Alaska, bearing the same switched (positive-negative) ion mass spectrometer. A super Arcas, launched 12-1/2 min after the 1980 Paiute Tomahawk flight, carried an rf-probe which provided electron concentrations. The 1980 event involved electron precipitation associated with a post geomagnetic storm. The 1981 flight occurred during quiet conditions.

The positive ion distributions determined for the two cases appear to qualitatively agree with current theories of the D-region. As usual, the heavier hydronium ions are observed to decline relative to lighter ions with decreasing altitude. An effect attributed to the break-up of heavier ions into lighter ions as pressure increases (altitude decreases). The current configuration for the mass spectrometer encompasses a cone shaped front to attach the shock to the rocket. During the 1979 eclipse program, this configuration was found[2] to yield negative ion signal levels which were three orders of magnitude less than an instrument with a blunt end. Mass resolution was sacrificed to increase signal for the cone case. Yet, positive ions were relatively unaffected, suggesting that pressure effects may not be entirely responsible for the behavior. Manipulation of the ion focusing fields can give a factor of ten increase in sensitivity.[2] More work is needed on the instrument for the improvement of the negative ion data. This need is especially acute, since in the 1981 flight, light ions with masses < 50 amu appear to be the dominant negative ions near 80 km in contrast to all prior flights. The light negative ions < 50 amu may well be mostly contaminant ions.

Nitric oxide profiles were deduced from both the 1980 and 1981 data. Not surprisingly, nitric oxide concentrations were higher for the earlier flight which occurred during disturbed conditions. Both profiles are compatible with the range of profiles deduced[9] from prior observations of D-region and lower E-region positive ions.

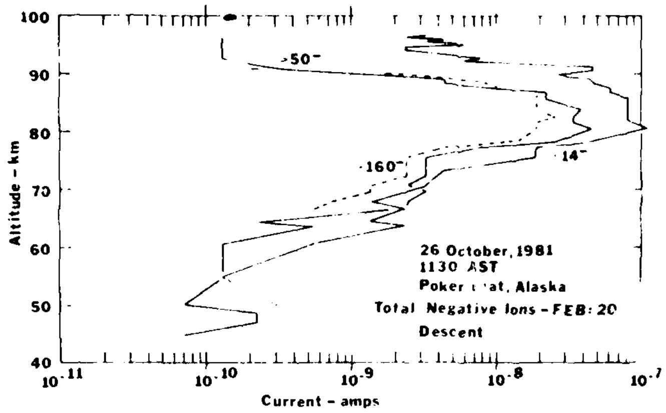

Figure 16. Total Currents for Negative Ions With Masses Exceeding 14, 50, and 160 amu Observed During Rocket A10.901-2 Descent, the Front End Bias Voltage Was 20 V

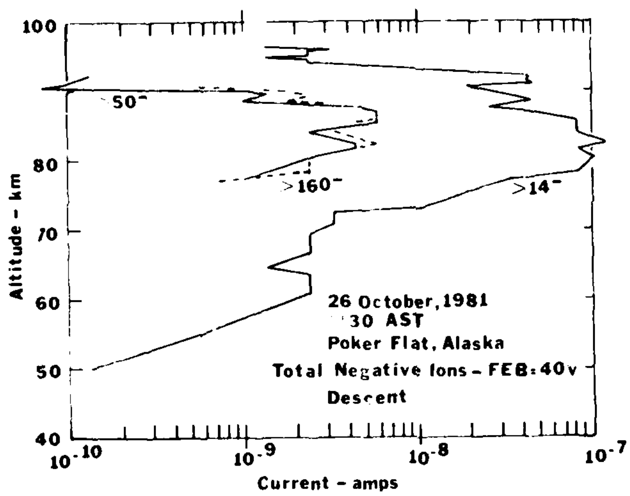

Figure 17. Total Currents for Negative Ions With Masses Exceeding 14, 50, and 160 amu Observed During Rocket A10.901-2 Descent, the Front End Bias Was 40 V

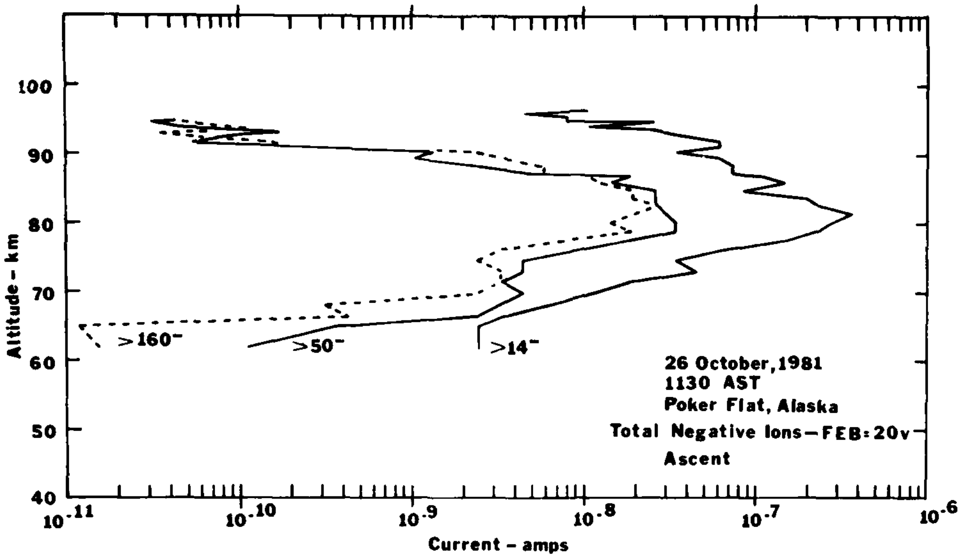

Figure 14. Total Currents for Negative Ions With Masses Exceeding 14, 50, and 160 amu Observed During Rocket A10. 901-2 Ascent, the Front End Bias of the Instrument Was 20 V

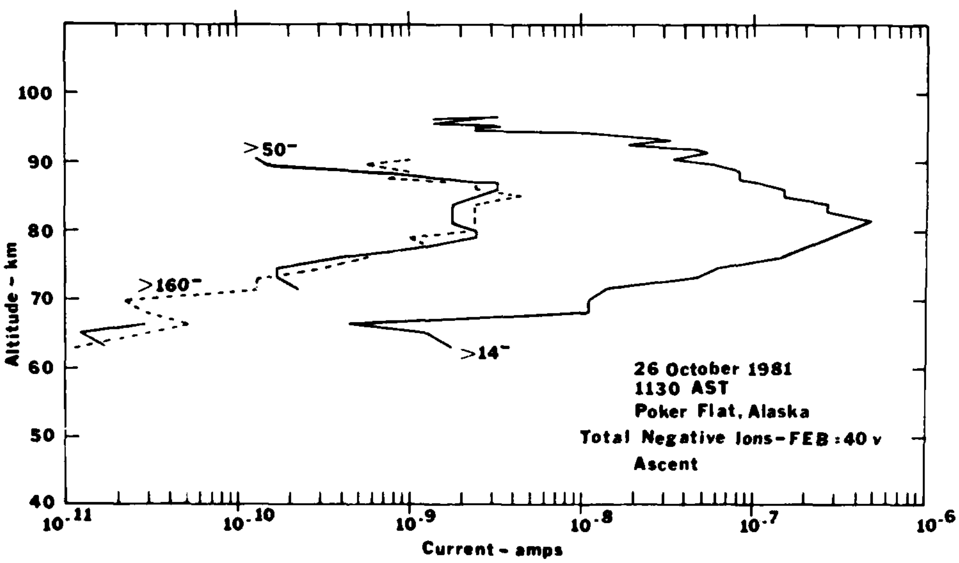

Figure 15. Total Currents for Negative Ions With Masses Exceeding 14, 50, and 160 amu Observed During Rocket A10. 901-2 Ascent, the Front End Bias of the Instrument Was 40 V

Negative ions with masses less than 14 are not expected. The present results show that most of the negative ions are between 14 and 50 amu. Some of the ions expected are O^- (16 amu), O_2^- (32 amu), Cl^- (35 and 37 amu) and NO_2^- (46 amu). What is striking about the current results is that lighter ions (between 14 and 50 amu) are predominant. This behavior was not observed in the eclipse or post-eclipse flights[2] of 1979 which used the same mass spectrometer configuration as here, nor in earlier flights[2] with a blunt front end. We cannot explain why the present results are different, but if these data are correct, the negative ion peak observed near 80 km may be related more to contamination than to an ambient phenomenon. The light ions O^- and O_2^- might be created during the measuring process because energetic electrons and O are present while Cl ions might be brought up with the rocket as a contaminant.[2] Further work still is needed in regard to determining the true ambient negative ion profiles in the D-region.

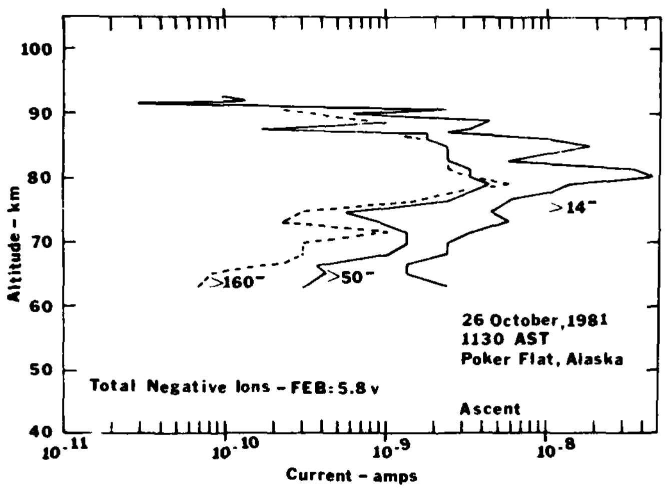

Figure 13. Total Currents for Negative Ions With Masses Exceeding 14, 50, and 160 amu Observed During Rocket A10.901-2 Ascent, the Front End Bias of the Instrument Was 5.8 V

of the high latitude winter ionosphere. This contrast is quite interesting since both flights were at the exact same (high) latitude in late October. The differences may be attributed to late October being near a transition time for changes in NO profiles at high latitudes. Other interpretations are undoubtedly possible.

10. NEGATIVE ION OBSERVATIONS

Negative ion currents are plotted for ascent in Figures 13 to 15 and for descent in Figures 16 and 17. Unfortunately, only total ion scans and not individual mass spectra were obtained. (Transmission is much greater for total ion measurements than for individual spectral scans.) Total ion measurements for ions within mass greater than 14 amu, 50 amu, and 160 amu were recorded for front end biases (FEB) of 5.8, 20, and 40 V. The cone placed on the front of the instrument to avoid shock breakup of ions apparently resulted in a much lower detection capability for negative ions.[2] An increase in the front end bias (FEB) voltage from 5.8 V to 20 V, induced little change in behavior except that more current was drawn at 20 V than 5.8 V. In addition, total ions > 14 amu fell off less rapidly with altitude for 20 V than they did for a 5.8 V FEB. An increase to 40 V from 20 V did not appreciably increase total negative ions exceeding 14 amu. However, fewer total ions were observed for mass groups exceeding 50 and/or 160 amu although, curiously enough, the ratio of these ions groups did not change to any significant degree. For downleg (Figures 16 and 17) there are no results for 5.8 V FEB, but the other results are comparable to the upleg data except that total ions > 14 amu have a smaller current on downleg.

Evidently, 20 V is better than 5.8 V for the front end bias (FEB) of an instrument with this configuration. Higher currents are observed with little change in the relative quantities of ions exceeding 14, 50 and 160 amu. For a 40 V FEB, the ionic groups with masses above 50 and 160 amu both show an order of magnitude loss of current. Presumably the 40 V FEB induces more collisions which break up most of the heavier ions into lighter ones that show up in the 14 amu group. However, no increase in this group is evident since they already are the major group at 20 V FEB by an order of magnitude.

survey of meteor ion data[14] indicates that maximum concentrations for these ions are about 1×10^3 cm^{-3} exclusive of meteor showers and D-region ionization enhancement events which can increase the charge transfer rate between neutral metallic atoms and O_2^+ and NO^+ ions. Hence, the metallic ion data might even suggest that we lower our conversion factor by two. But precipitation effects over the 24 hours prior to the flight may have elevated the metallic ion concentrations somewhat. In any case, we will adopt the 4×10^9 ions/ampere conversion factor but with the understanding that it is uncertain to about a factor of two for altitudes down to 80 km. The decrease in ion current below 80 km is presumably not linearly correlated with the total ion concentration since a value of only 3×10^{-9} A is attained by 75 km and our conversion factor would imply a concentration of 12 ions cm^{-3}. This value is at least a factor of ten too low. Insufficient vacuum in the instrument is presumably the reason for this low value.

9. NITRIC OXIDE CONCENTRATIONS FOR FLIGHT OF ROCKET A10.901 - 2

Our conversion factor of 4×10^9 ions cm^{-3}/A yields total ion concentrations of about 8×10^3, 4×10^3, 2.4×10^3, and 5×10^2 cm^{-3} for altitudes 95, 90, 85, and 80 km, respectively. Applying the logic used in deriving nitric oxide concentrations for the first rocket (see Section 4), we determined the following NO con-concentrations for 95, 90, 85, and 80 km, respectively: 8×10^7, 3×10^7, 2×10^7, and 2×10^6 cm^{-3}.

Since the NO^+/O_2^+ ratio was very large, the first term in Eq. (1) is basically negligible, that is, all NO^+ originates from the ionization of NO with a negligible contribution from $O_2^+ + NO \rightarrow NO^+ + O_2$. This fact puts us at some variance with our use of the E-region model of Keneshea et al[12] as a total ion concentration reference since in their work the NO^+/O_2^+ ratio was about 10 at 85 and 95 km and about 10^2 at 90 km whereas we observed high ratios of roughly 300, 200, 400 and 10^3 for 80, 85, 90, and 95 km, respectively. However, Keneshea et al[12] did claim the use of a somewhat higher than average X-ray ionization source. For negligible O_2^+, NO in Eq. (1) is directly proportional to the square of the electron concentration since $[NO^+] \approx [e]$. Thus, the precision of our [NO] estimates is very dependent upon our estimates for [e]. If our [e] values are accurate to a factor of two, as we believe, our [NO] estimates are imprecise by at least a factor of four. The [NO] values reported above are more consistent with results[7] for the mid-latitude ionosphere than the previous flight which was noted as more characteristic

14. Swider, W. (1984) Ionic and neutral concentrations of Mg and Fe near 92 km, Planet. Space Sci. 32:307-312.

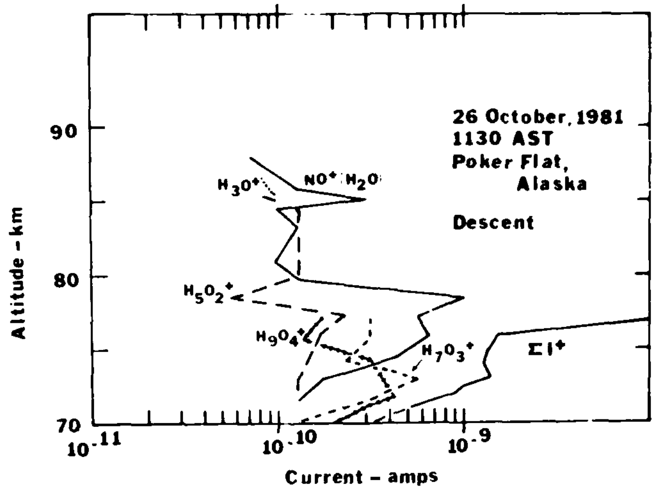

Figure 12. Mass-spectrometric Currents Measured for Hydronium Ions and $NO^+ \cdot H_2O$ During Descent of Rocket A10.901-2

8. TOTAL POSITIVE ION CONCENTRATIONS FOR ROCKET A10.901 - 2

Since neither the Gerdien condenser data nor the retarding potential analyzer data have been completely reduced to date, we must resort to an estimate for the total positive ion concentrations during this flight. As this mass spectrometer was the same one flown on the previous flight, a conversion factor of 10^{10} ions cm^{-3}/A, as estimated earlier would lead to fairly reasonable ion concentrations. However, the instrument sensitivity was changed slightly in the laboratory and a factor of 2×10^9 ions cm^{-3}/A appears to be more appropriate. From a diurnal model[12] of the mid-latitude E-region, we estimate total ion concentrations of about 8×10^3, 4×10^3, and 2×10^4 cm^{-3} for 95, 90, and 85 km, respectively, for a SZA of 77°. These values compare well with an Arecibo radar[13] study. To obtain such concentrations from the ascent data (Figure 8), the current in the figure needs to be multiplied by 4×10^9 ions cm^{-3}/A. The meteoric ion data also offer a clue to total ion concentration. If we use the latter conversion factor, peak currents of about 4×10^{-7} A for Mg^+ ions and 5×10^{-7} A for Fe^+ ions yield peak concentrations of 1.6×10^3 and 2×10^3 cm^{-3}, respectively, for Mg^+ ions and Fe^+ ions. A recent

12. Keneshea, T.J., Narcisi, R.S., and Swider, W. (1970) Diurnal model of the E-region, J. Geophys. Res. 75:845-854.

13. Trost, T.F. (1979) Electron concentrations in the E- and upper D-region at Arecibo, J. Geophys. Res. 84:2736-2742.

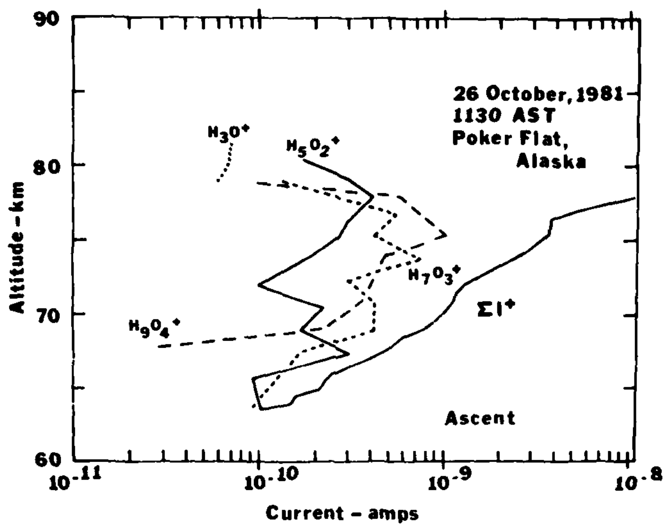

Figure 10. Hydronium Ion Data Acquired During Rocket A10.901-2 Ascent

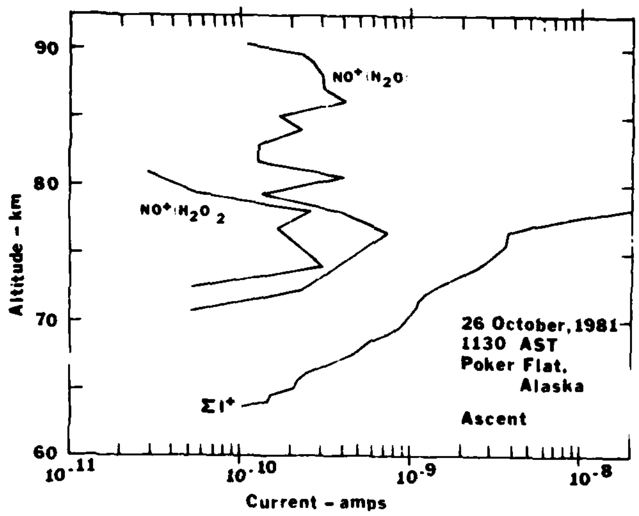

Figure 11. Hydrated-NO^- Data Acquired During Rocket A10.901-2 Ascent

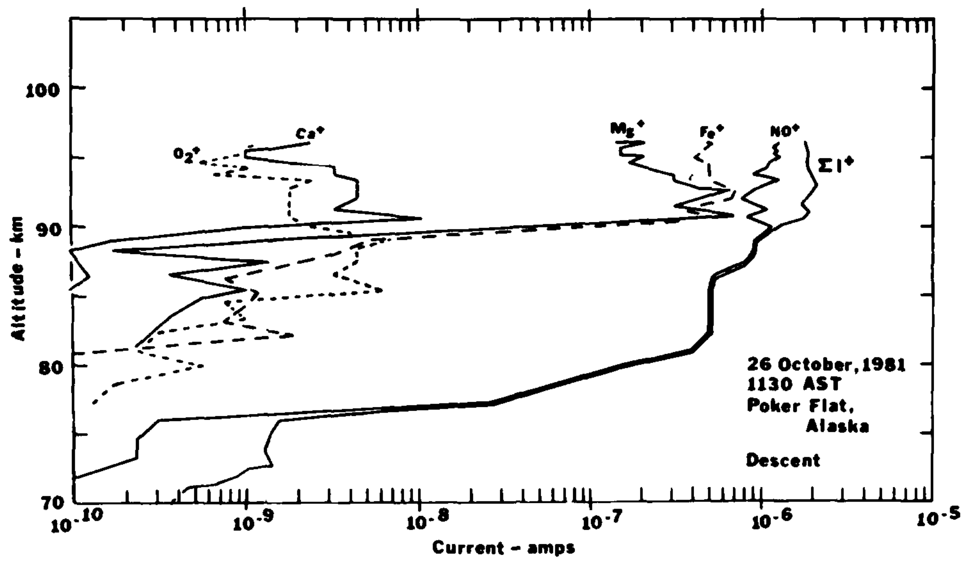

Figure 9. Positive Ion Data Obtained During Rocket A10.901-2 Descent

that $H_9O_4^+$ rapidly becomes the most prominent hydronium ion with decreasing height. Our data roughly follow this behavior although especially on ascent, lighter hydronium ions begin to become more prominent with decreasing height. We believe this pattern reflects the breakup of hydronium ions due to shock effects, which increase with decreasing altitude. Such effects should be similar on ascent and descent for a gyrostabilized rocket like this one. Many of the chemical reaction rates leading from NO^+ to $H_7O_3^+$ are yet unmeasured, so further analysis of these data beyond a qualitative assessment appears to be unfeasible.

Nitric oxide ions are the dominant ions down to about 77 km on both ascent and descent. This behavior indicates that conditions for the conversion of NO^+ ions to hydronium ions are not as favorable as they might have been since the transition altitude is commonly near 82 km. This pattern is also evident in the "warm, wet" model of Reid. The "warm" factor is probably more critical than the quantity of water especially since in Reid's modelling work, "wet" and "dry" are perhaps not as divergent as one might think. They refer to water vapor mixing ratios of 9 ppmv and 1.2 ppmv, respectively, at 60 km, with lower mixing ratios for both near 80 km. It is not clear that the D-region is ever as dry as 1.2 ppmv at 60 km and about 0.3 ppmv at 80 km. Even the so-called "wet model" only has about 3 ppmv $[H_2O]$ at 80 km.

7. POSITIVE ION RESULTS FROM ROCKET A10.901 - 2

Ascent and descent total ion currents obtained with the mass spectrometer are shown in Figures 8 and 9, respectively. The key feature in both figures is the dominance of NO^+ ions from apogee down to about 77 km. This behavior may be characteristic of the quiet wintertime D-region. The NO^+/O_2^+ ratio exceeds 100 at all altitudes above 77 km both on ascent and descent. The concentration of the ions associated with major meteoric elements are nearly equal to $[NO^+]$ at around 91-93 km, the common altitude for metallic ions of meteoric origin.

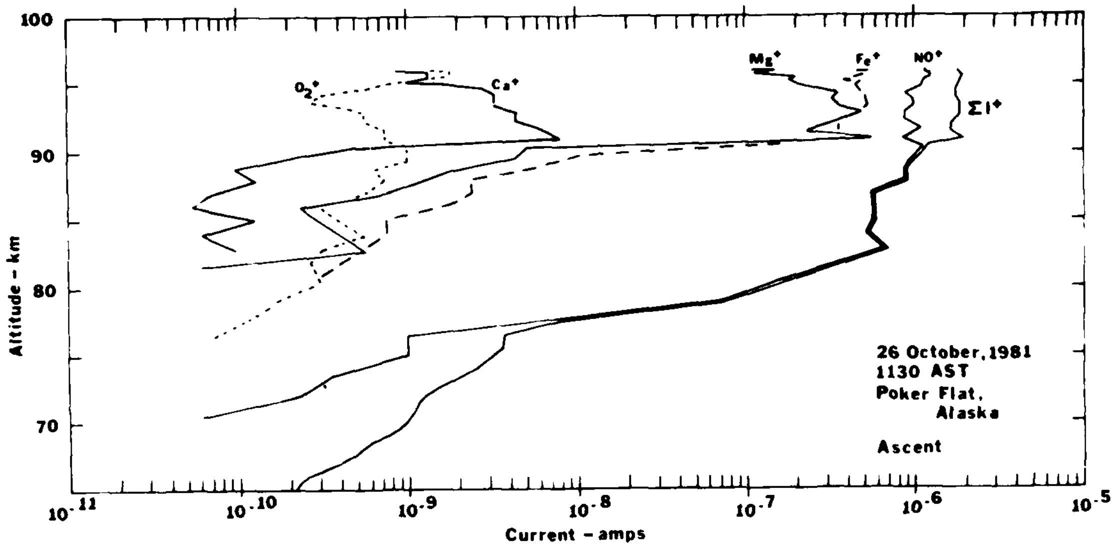

Figure 8. Positive Ion Data Obtained During Rocket A10.901-2 Ascent

The so-called water cluster ions (the oxonium ion and its hydrates, the hydronium ions) and NO^- hydrates are depicted in Figures 10 to 12 for both the ascent (Figures 10 and 11) and the descent portions of the flight. Reid[11] has made various calculations of the positive ion structure of the quiet D-region. Very roughly, the data presented for this flight appear to qualitatively agree best with his "warm, wet" model. For that model, $NO^-(H_2O)$ is present up to 90 km and is much more prominent than $NO^-(H_2O)_2$ which first appears at a lower altitude than does $NO^-(H_2O)$, a behavior in accordance with the data here. In addition, he finds

11. Reid, G.C. (1977) The production of water-cluster positive ions in the quiet daytime D-region, Planet. Space Sci. 25:275-290.

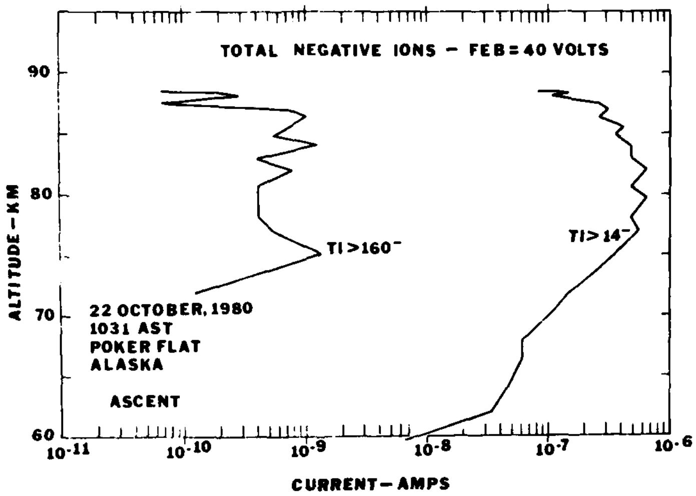

Figure 7. Total Currents for Negative Ions With Masses Greater Than 14 amu and 160 amu Observed During Rocket A10.901-1 Ascent, the Front End Bias Was 40 V

6. INTRODUCTION TO THE 1981 FLIGHT

In the preface, we pointed out that we just missed launching into an SPE. We decided to launch the ready payload into the quiet D-region for background purposes. The mass spectrometer flown was the same instrument used previously. The rocket, designated A10.901-2 by AFGL, was launched at 1130 AST on 26 October 1981 from Poker Flat, Alaska. The solar zenith angle (SZA) was 77.6°. This SZA is almost exactly that of the 1980 flight which was a few days earlier in October, and an hour earlier, but further from true solar noon, about 1115 AST. The rocket had the same payload as the previous Paiute Tomahawk. Only the mass spectrometric results are considered in this report. The other measurements have not yet been completely reduced. The rocket attained an apogee of 96.1 km at 156 sec after launch. (The SZA was still at 77.6°.) The angle of attack between the velocity vector and the normal to the mass spectrometer's entrance hole was 13° at most, mainly at apogee, but generally less on both ascent and descent for this gyro-stabilized vehicle. Unlike the previous year, a second rocket bearing other instrumentation was not launched.

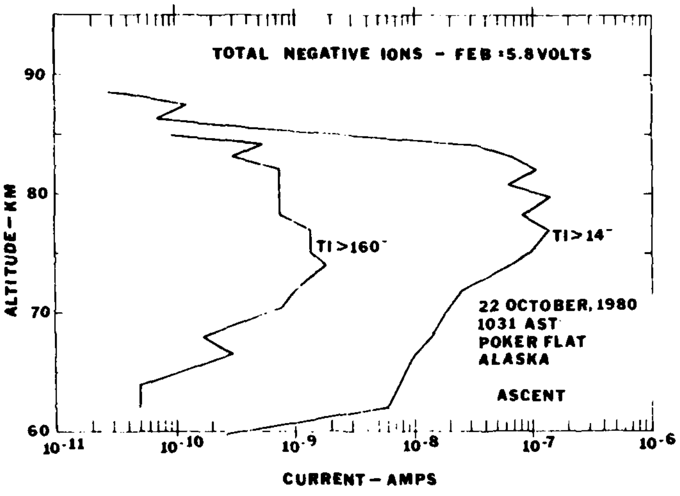

Figure 5. Total Currents for Negative Ions With Masses Greater Than 14 amu and 160 amu Observed During Rocket A10.901-1 Ascent, the Front End Bias Was 5.8 V

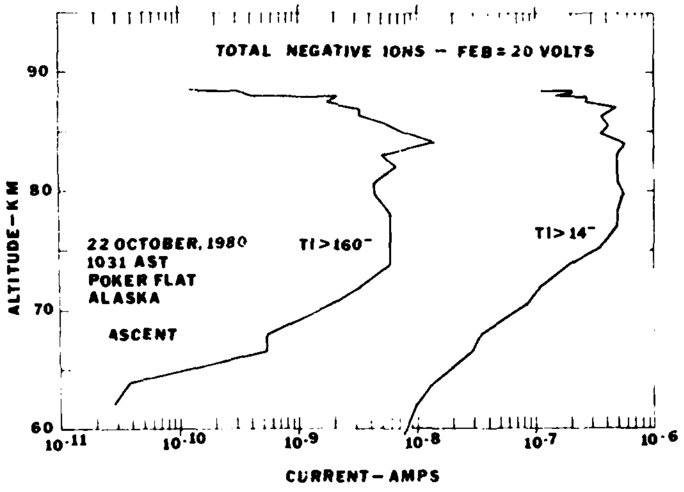

Figure 6. Total Currents for Negative Ions With Masses Greater Than 14 amu and 160 amu Observed During Rocket A10.901-1 Ascent, the Front End Bias was 20 V

Using the 1976 U.S. Standard Atmosphere for temperature and $[O_2]$, we estimate 6×10^7, 8×10^7 and 1.6×10^8 cm^{-3} for NO at 80, 85 and 90 km, respectively, based upon electron concentrations [e] of 4×10^3, 4×10^4 and 1.1×10^5 cm^{-3} for these same altitudes. These [e] are an average of the Super Arcas upleg observations and our estimate for the total positive ion concentrations. The major uncertainty in the estimate for [NO] is the uncertainty in [e]. There is also some uncertainty in the actual neutral atmosphere parameters T and $[O_2]$. The $q(NO^+)$ term in Eq. (1) was of no importance in the value derived for [NO] at 90 km but decreased the estimate for [NO] by 5 and 50 percent, respectively, at 85 and 80 km. For the quiet D-region results discussed later in this report, the $q(NO^+)$ term is the dominant NO^+ source.

Our estimates of [NO] are accurate to about a factor of two, an uncertainty mainly related to the uncertainty in [e]. These NO conventrations are large in comparison to those at mid- and equatorial latitudes. However, they are consistent with the larger concentrations associated with high latitudes, particularly in winter, when photodissociation of nitric oxide by sunlight is less prevalent. For 22 October 1980, at Poker Flat, Alaska (65°N), the minimum solar zenith was 76.3°. The sun was above the horizon for 8-2/3 hours. The nitric oxide concentrations derived here are within a factor of two of those derived[9] from a late January 1971 program by NASA at 47°N.

5. *NEGATIVE ION DATA (A10.901 - 1)*

Ascent data for total negative ions are shown in Figures 5, 6 and 7. The front end bias (FEB) for the instrument was at 5.8, 20 and 40 V, respectively, for each figure. The mass resolution of this instrument had been lowered considerably[2] in order to increase signal amplitudes. From the eclipse program, it was found[2] that this type of instrument configuration with a conical front end had signal amplitudes three orders of magnitude less than did a blunt front end configuration. Hence, negative ions were measured only in the total ion mode. Totals are shown for all ions with masses above 14 amu and 160 amu. Spectra were too poor (low counts) to discern which ions were prominent. The major ions clearly lay between 14 and 160 amu. Further discussion will take place with regards to the data of the second flight discussed next.

the rocket-based measurements. Chatanika results[7] around the time of apogee for the Paiute-Tomahawk flight give electron profiles which appear to be displaced downward by a few kilometers from the rocket data. Thus, a Chatanika radar concentration of 5×10^4 cm^{-3} for 78 km is not appropriate. The ion concentration (Figure 1) is clearly less.

4. NEUTRAL NITRIC OXIDE ESTIMATES FROM DATA OF ROCKET A10.901 - 1

Neutral nitric oxide concentrations, [NO], can be derived for lower ionospheric heights where O_2^+ and NO^+ are major ions. Such calculations have been made in the past for the auroral E-region[8] and the quiet upper D- and lower E-regions.[9] The continuity equation for NO^+ ions[9] is

$$k[O_2^+]\,[NO] + q(NO) = \alpha(NO^+)\,[e]\,([NO^+] \qquad (1)$$

where

$$q(NO^+) = 6 \times 10^{-7}\,[NO]\exp(-10^{-20}[O_2]H\ F)\ . \qquad (2)$$

The rate coefficient k of the charge transfer process $O_2^+ + NO \rightarrow NO^+ + O_2$ is about 4.4×10^{-10} cm^3/s. The dissociative recombination coefficient, $\alpha(NO^+)$ is about $4 \times 10^{-7}(300/T)$. The $q(NO^+)$ equation accounts for those nitric oxide ions which originate from the photoionization of NO by the HL$\gamma\alpha$ line. The nominal HL$\gamma\alpha$ intensity 3×10^{11} photons/cm^{2}s, multiplied by the ionization cross section for NO, 2×10^{-18} cm^2, yields the 6×10^{-7} s^{-1} factor in Eq. (2). The exponent 10^{-20} $[O_2]$ H F accounts for the attenuation of the HL$\gamma\alpha$ line by O_2 with an absorption cross section of 10^{-20} cm^2. The term $[O_2]$HF is the absorption column, cm^{-2}, of O_2, with $[O_2]$ being the concentration of O_2 in cm^{-3} at altitude, H the local scale height of the atmosphere (since it is mixed below about 100 km) and F the optical depth factor,[10] which is the secant of the solar zenith angle, χ, if $\chi < 75°$.

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