Committie on Space Research
(COSPAR) 16-18 June 1971
Boston MA

Contents

29. Positive Ion Composition of the D and E Regions During a PCA

R.S. Narcisi, C.R. Philbrick, D.M. Thomas,
A.D. Bailey, L.E. Wlodyka, D. Baker,
G. Federico, R. Wlodyka and M.E. Gardner
Air Force Cambridge Research Laboratories
L.G. Hanscom Field
Bedford, Massachusetts

Abstract

Positive ion composition measurements were obtained from three rocket flights in the D and E regions over Ft. Churchill, Canada during the 2-4 Nov 1969 PCA event. The rockets were launched at 0130 CST (0.4 dB) and 1130 CST (3 dB) [30 MHz riometer absorptions in parentheses] on 3 November and at 1650 CST (0.7 dB) on 4 November. Results from the nighttime measurements between 62 and 139 km showed that water cluster ions were predominant below 77 km and that NO^+ and O_2^+ were the major ions from 77 to 139 km. A class II^+ aurora was also in progress during the night flight as evidenced by the total ion density, which attained a maximum of 8×10^5 ions/cm^3 at 122 km and exceeded 10^5 ions/cm^3 between 105 and 127 km. Daytime and sunset measurements were made between 73 and 144 km and between 78 and 144 km, respectively. NO^+ and O_2^+ were dominant ions down to the lower altitude measurement limits of both flights. The persistent broad meteoric ion layer centered near 95 km, and submerged thin layers of meteoric species at higher altitudes were measured in all flights. Previous measurements obtained under more quiescent conditions are compared to the PCA measurements.

29-1 INTRODUCTION

During the 2-4 November 1969 PCA event at Ft. Churchill, Canada, three rocket measurements of the D and E region positive ion composition were performed with cryopumped, quadrupole mass spectrometers. Each rocket payload contained a mass spectrometer, a cylindrical Langmuir probe, a gyro aspect system, radar beacon and FM/FM telemetry. The first mass spectrometer was launched on November 3 at 0130 CST, the second was fired 10 hours later at 1130 CST, and the third was launched at sunset at 1650 CST on November 4. Table 29-1 gives other pertinent flight details. The results of the mass spectrometer measurements are presented and are compared with previous measurements obtained over Ft. Churchill and at mid-latitudes during more quiescent conditions.

Table 29-1.

Rocket	Launch Time Date	Solar Zenith Angle	Zenith Riometer Absorption (dB)*	Mass Range (amu)	Total Ion Step(s)	Mass Scan Time (Sec)
AG7.882	0730Z 3 Nov 69	133^o	0.4	13.5 - 108.5	>34 amu >50 amu	2.6
AH7.886	1730Z 3 Nov 69	74^o	3.0	9.5 - 71.5	41.5 amu	2.0
AH7.893	2250Z 4 Nov 69	94.6^o	0.7	12.5 - 67.0	42 amu	1.5

*R. Cormier, these proceedings.

29-2 EXPERIMENTAL METHOD

The cryopumped positive ion mass spectrometer has been described elsewhere (Narcisi and Bailey, 1965; Bailey and Narcisi, 1966). Table 29-1 also lists the mass ranges, total ion transmission steps, and the mass scan times for the three instruments flown. The mass range was periodically swept and followed by the total ions step(s) in the times noted. The mass spectrometer on AG7.882 had two total ion steps. Figure 29-1 shows this feature and gives examples of D and E region flight spectra. In each step the draw-in potential imposed on the surface containing the ion entrance aperture was varied from +4 volts to -19 volts in order to examine the fragmentation of cluster ions caused by the sampling electric field (Narcisi, 1970). In all other cases the draw-in potential was fixed at about -10 volts. A vacuum cap seal was ejected with the nose cone in the vicinity of

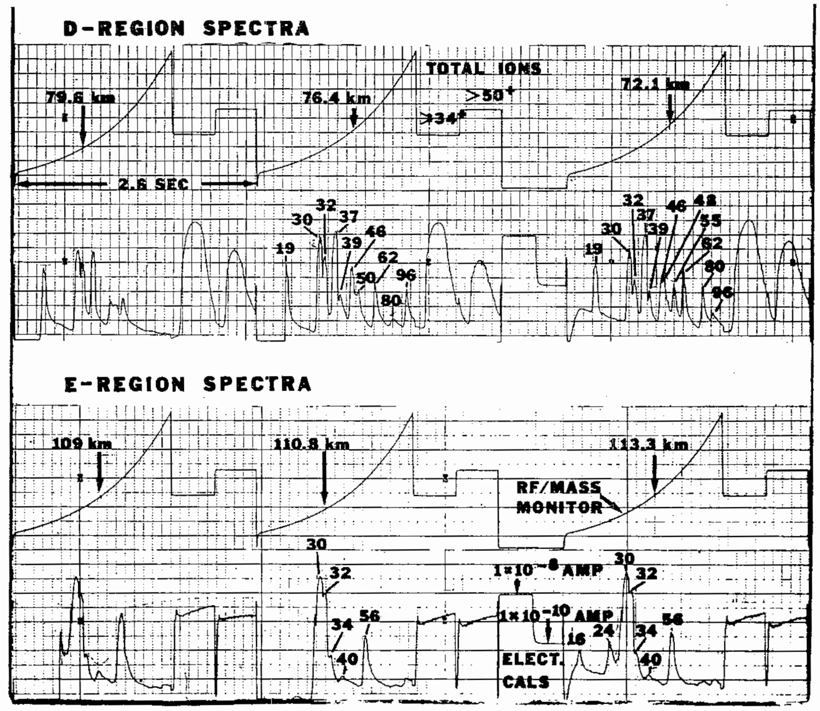

Figure 29-1. Flight Mass Spectra Obtained in the D and E Regions on Rocket AG7. 882

72 km on vehicle ascent to expose the 0. 030 in. diameter mass spectrometer sampling orifice.

29-3 DATA AND ANALYSIS

The measured mass peak ion currents for each species were plotted as a function of altitude, and straight lines were drawn to connect adjacent data points. These profiles were then normalized for vehicle speed and vehicle attitude by the method outlined by Narcisi (1971). The normalized currents of all species were summed at each altitude and the resulting profile was multiplied by a constant factor to obtain profiles of ion density vs altitude. This constant factor was derived from electron density measurements with Langmuir probes, 3-frequency beacons, and ion mass spectrometer sensitivities. Other details and uncertainties in this method may be found in Narcisi (1971). Generally, except where indicated otherwise, the error in the absolute concentrations is less than or about ± 30 percent. The altitude error is probably less than 0. 2 km.

The positive ion mass numbers and identifications of species measured in the D and E regions are listed here for future reference: $16(O^+)$, $19(H_3O)^+$, 24(Mg^+), 27(Al^+), 28(N_2^+ or Si^+), 30(NO^+), 32(O_2^+), 34($^{16}O\,^{18}O^+$), 37($H_5O_2^+$), 39($H_5\,^{16}O^{18}O^+$), 40(Ca^+), 46(NO_2^+), 48($NO^+ \cdot H_2O$), 50($O_2^+ \cdot H_2O$), 55($H_7O_3^+$), 56(Fe^+), 62 ± 1 (?), 72(FeO^+), 80 ± 1 (?), 96 ± 1 (?). The unidentified mass numbers, 62 and 80, are separated by 18 amu, possibly suggesting a hydrated species.

29-4 RESULTS

29-4.1 AG7.882

Figure 29-2 gives the ascent results obtained between 72 and 139 km from the night flight of rocket AG7.882. The zenith riometer absorption was 0.4 dB.

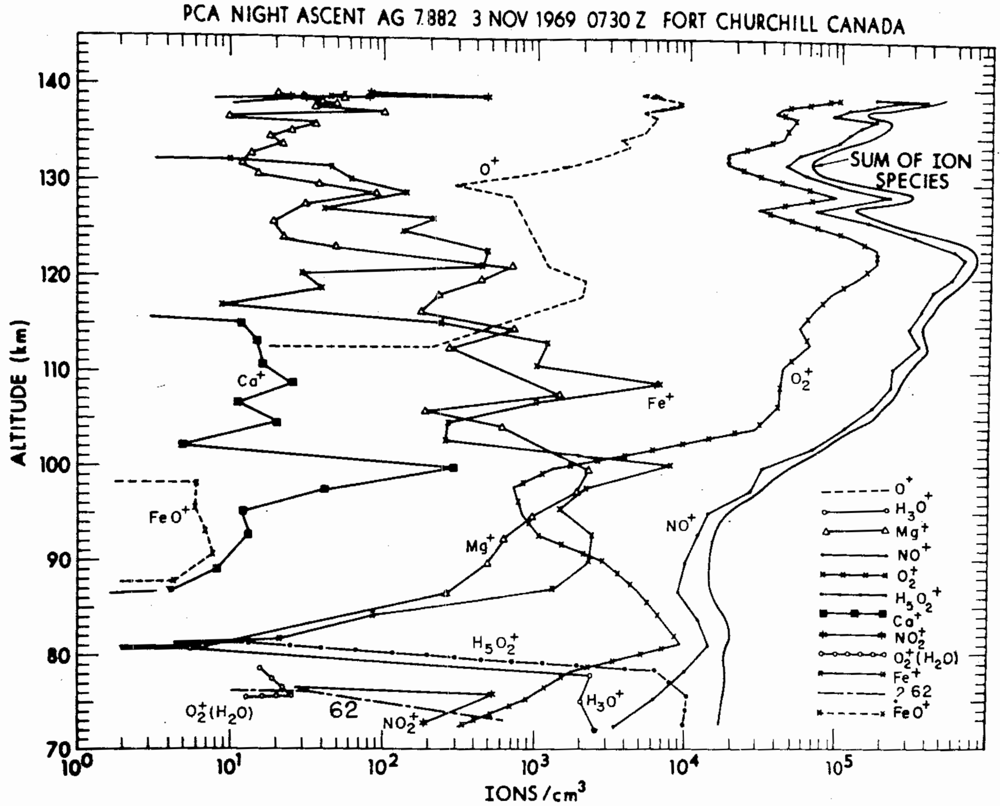

Figure 29-2. The Positive Ion Composition in the Nighttime D and E Regions During a Simultaneous PCA Event and Auroral Event

The ion concentrations in both the D and E regions were greatly enhanced. Below 90 km, the ion concentrations were increased by more than 100 times normal due to proton ionization. The most striking of the results in the D region was the significant change in the water-cluster ion distribution. Water-cluster ions normally dominate the nighttime D region below 86 km (Narcisi, 1971; Narcisi et al, 1972). But Figure 29-1 shows that under these disturbed conditions water-cluster ions are predominant only below 77 km and that NO^+ and O_2^+ are the major ions above this altitude.

The results between 90 and 100 km which include the main meteoric layer are typical of measurements obtained during more quiescent conditions at Ft. Churchill (Narcisi, 1971). Submerged sporadic E- like layers of meteoric species were present up to apogee. Above 100 km, the ion concentrations were again significantly increased and attained a maximum of 8×10^5 per cm^3 at 122 km. This ion density is indicative of an IBC class II^+ aurora which was most likely produced by energetic electrons. Overcast skies prevented ground-based optical observations of auroral activity.

Energetic electrons and increased charged-particle concentrations in the E region were measured by a Black Brant rocket payload fired 1 hr 25 min earlier (Ulwick, 1972). No such measurements were available for the time of this rocket flight. Unfortunately, the Langmuir probe failed so that no other charged-particle profile was available for comparison. The Ft. Churchill ionosonde, however, indicated that strong auroral activity was present. Figure 29-3 shows three ionograms taken during the flight of this rocket. Typical of a PCA event, the lower frequency radiation is absorbed, but in the vicinity of 120 km strong auroral pulsations were observed with returns up to and exceeding 16 MHz. It is, however, not possible to obtain reliable quantitative values from these ionograms to apply to the flight results.

Measurements were obtained on downleg to 62 km on rocket AG7. 882. Figure 29-4 gives the uncorrected currents for the various species vs altitude on descent, and the figure demonstrates the complexity of the D region. The identifications listed previously apply for the mass numbers shown. The rocket was backing into the atmosphere, and as the rocket's speed increased on descent the currents were increasingly reduced. The rocket began turning over at 82 km and by 78 km the instrument was pointed into the direction of motion and the currents increased markedly.

There are several difficulties associated with the D region measurements that are worthy of discussion. The true relative abundance of the ion species in the D region is distorted by the rocket sampling method which causes a breakup of the cluster ions. Because the ion clusters, and especially the larger ones, are weakly bound, they can be torn apart by collisions in the shock-heated gas and/or by collisional fragmentation after the ion gains sufficient energy in the sampling electric field (Narcisi, 1970; Narcisi and Roth, 1970). Typically, water molecules are

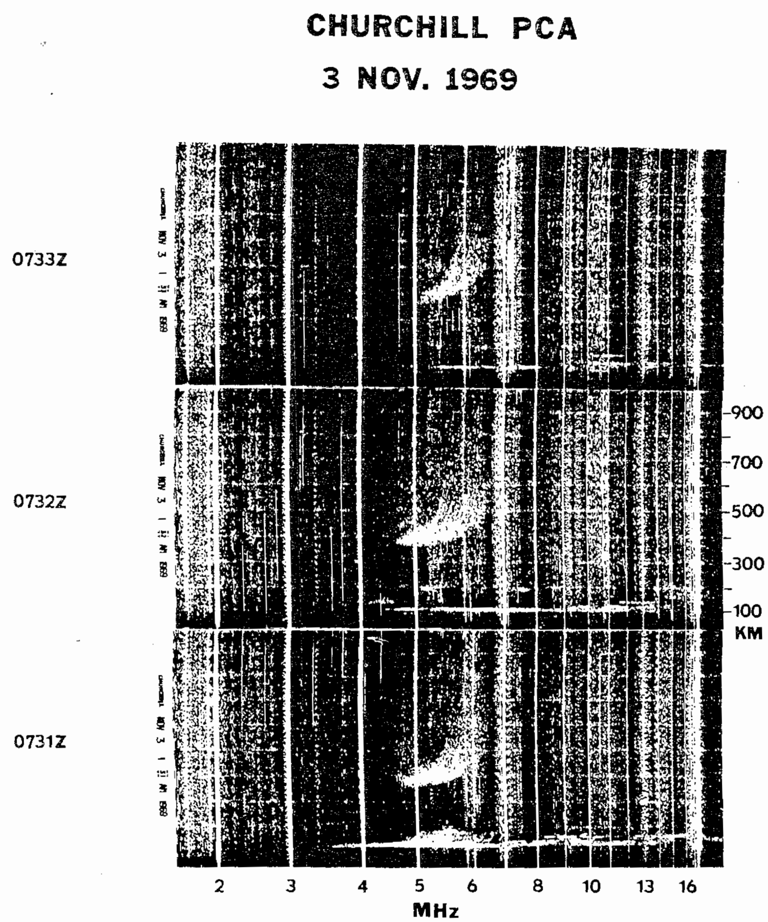

Figure 29-3. Ionograms Indicating Auroral Activity During the Flight of Rocket AG7. 882

broken off the cluster ion in these processes. The decrease in ion species currents below about 72 km, as seen in Figure 29-4, was due to increasing pressure in the mass spectrometer and collisional loss of ions from the ion beam. The heavier ions with the larger collisional cross sections, were affected most. The measured lighter mass ions below 70 km were most likely the fragments of heavier ones.

29-4.2 AH7.886

Figure 29-5 presents the ascent results obtained between 73 and 144 km from the daytime flight during which the zenith riometer absorption was 3 dB. There are two peculiarities in the results shown in Figure 29-5. First, the decrease in concentrations below 80 km is not actual, but was due to high pressure in the quadrupole resulting from the slow pump recovery after the pressure burst on nose-cone

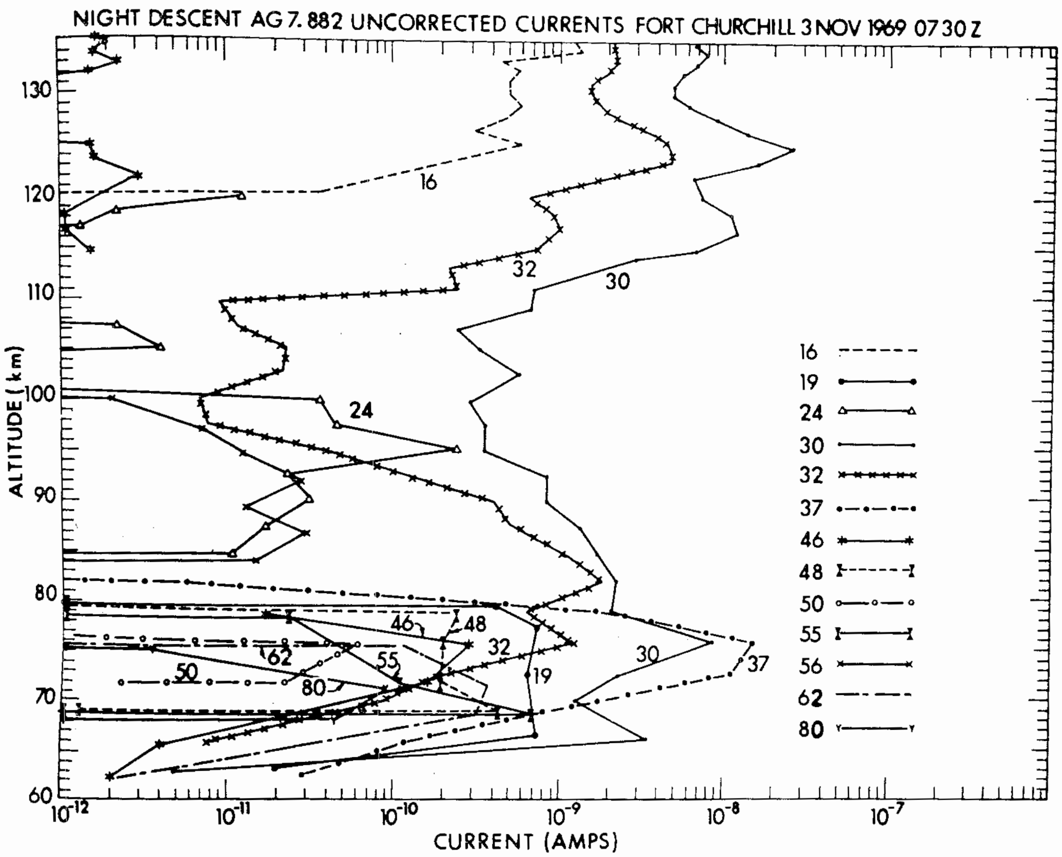

Figure 29-4. D and E Region Positive Ion Composition Measurements Obtained on Downleg of Rocket AG7.882 During a PCA

ejection. Secondly, the modulations in the data were produced by the spin of the vehicle and azimuthal variations in ion transmission of the quadrupole, especially at large angles of attack. This is difficult to correct. Although not performed here, smooth profiles may be determined by utilizing the relative composition which is considerably less modulated and then normalizing the relative abundances to the total density profile determined from the Langmuir probe measurements. The altitude profile of the NO^+/O_2^+ ratio for this flight generally exhibits less than a 20 percent modulation. On the other hand, mean profiles could simply be drawn through the modulated ones in Figure 29-5, and the results generally would not deviate by more than a factor of two from these mean curves.

There are several interesting features in the daytime flight results. NO^+ and O_2^+ were the major ions over the entire altitude range with O_2^+ dominating only between 78 and 90 km. During normal daytime conditions at mid-latitudes, water-cluster ions predominate below about 82 km (Narcisi et al, 1972). The concentrations

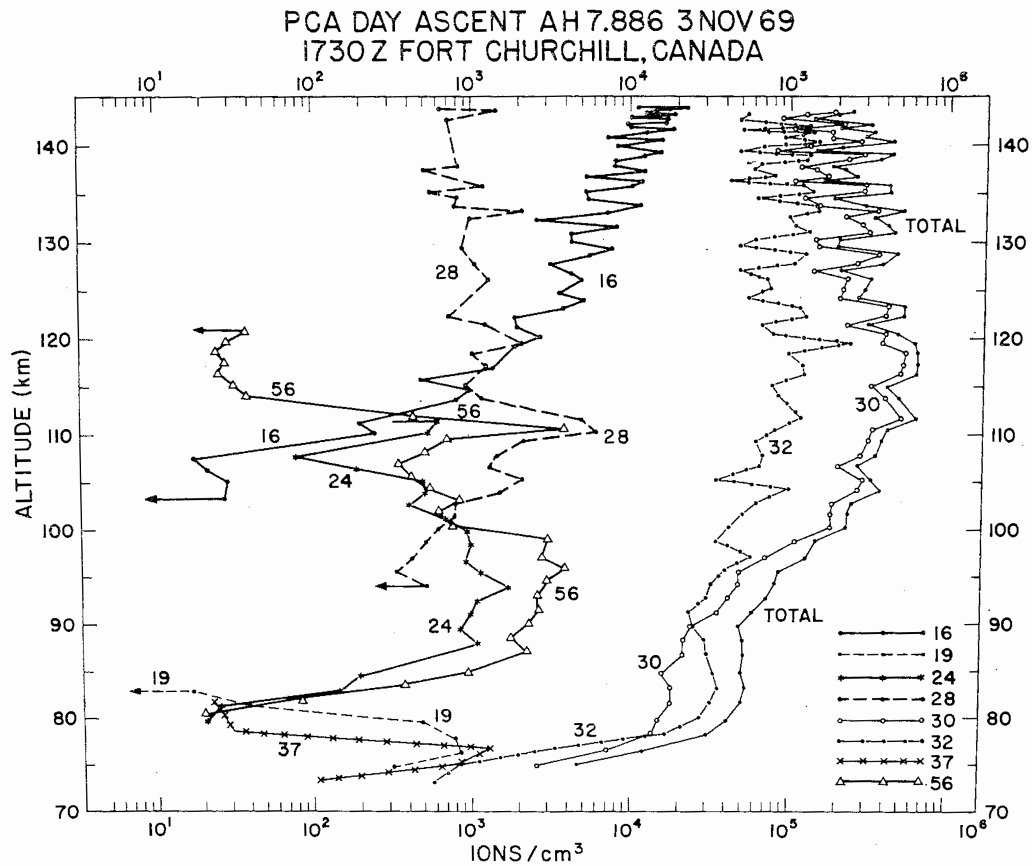

Figure 29-5. Daytime Positive Ion Composition of the D and E Regions During a PCA

of H_3O^+ and $H_5O_2^+$ in the day flight are similar to those during quiescent midday and mid-latitude conditions, but their concentrations are considerably smaller than the previous night flight values (compare Figures 29-2 and 29-5).

The iron and magnesium ions in the main meteoric band around 95 km were in about the same concentrations as in the nighttime flight; aluminum and calcium ions were also measured but are not plotted in Figure 29-5. An upper layer of meteoric species was located at 109 km at night; another one was measured at 110.5 km 10 hours later. Also note that the major ion in the daytime layer was silicon (28^+). Mass 28 above and below the layer was most likely N_2^+.

The diurnal model of the E region of Keneshea et al (1970) predicts ion densities somewhat less than 10^5 cm^{-3} above 95 km for the normal solar flux at the solar zenith angle for this flight (74^o). In the PCA daytime flight the ion densities were greater than 10^5 cm^{-3} above 96 km and as high as $5\text{-}6 \times 10^5$ cm^{-3}. Even applying the factor of two error reduction in density does not reduce the concentrations sufficiently; therefore, it is believed that energetic electrons created most of the E region ionization during the daytime flight.

29-4.3 AH7.893

Figure 29-6 presents the ascent results between 78 and 144 km from the rocket flown near sunset on November 4 when the zenith riometer absorption was 0.7 dB. The results showed considerable variations above 112 km; however, again the NO^+/O_2^+ ratio was not as seriously modulated. Only a trailing off of the water-cluster-ion ledge was seen between 78 and 86 km. NO^+ and O_2^+ were generally the dominant ions over the D and E regions with meteoric ions also present in significant concentrations between 90 and 104 km. O^+ was less than 2-3 percent of the total density.

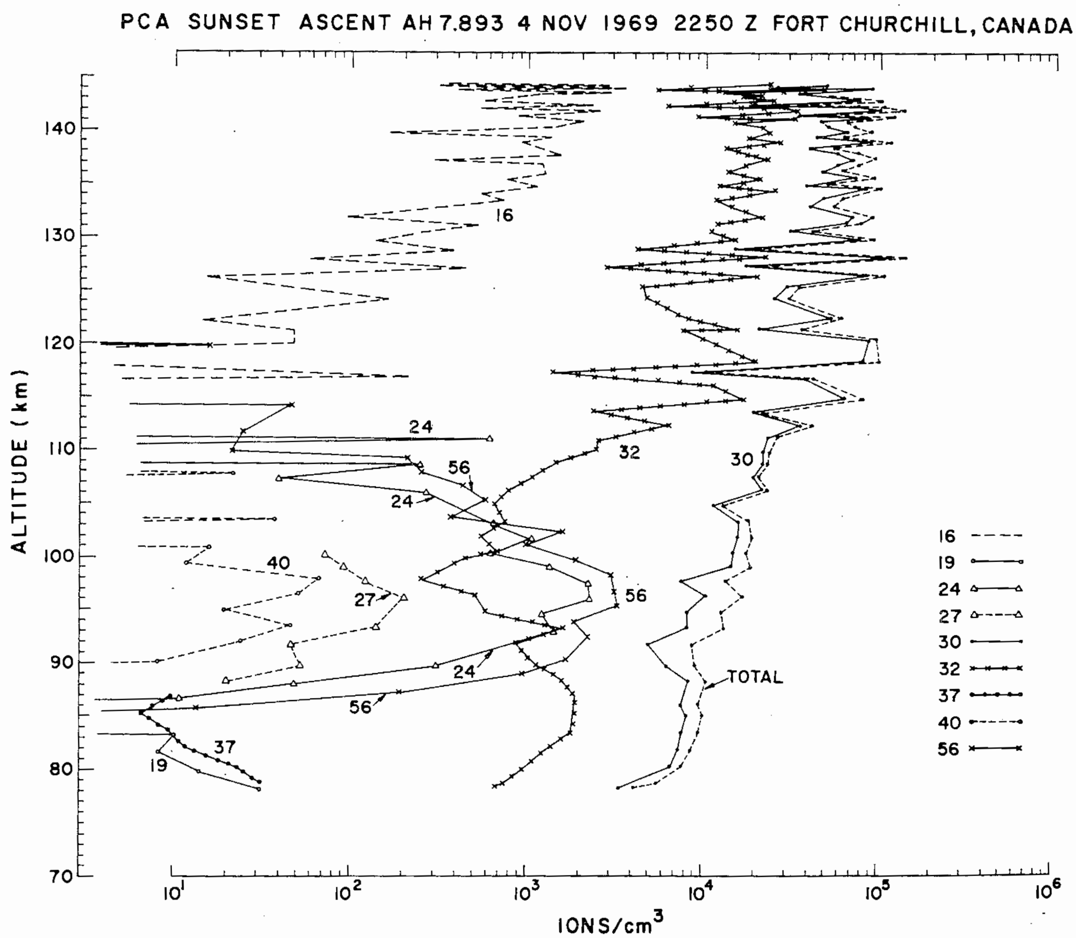

Figure 29-6. Sunset Positive Ion Composition of the D and E Regions During a PCA

A comparison of the results from this rocket flight launched at 94.6° solar zenith angle with the results from a sunset flight launched at 96.4° on 4 Dec 1967 from Ft. Churchill during more quiescent conditions is quite interesting. The 1967 results above 85 km (Narcisi, 1971, Figure 15) are essentially identical to those in Figure 29-6, considering the errors in absolute densities. However, below 86 km, the 1967 measurements (Narcisi, 1971, Figure 14) indicated that water-cluster ions ($H_5O_2^+$) were the dominant ions up to 86 km. In the PCA sunset flight, water cluster ions were present in extremely small concentrations down to 78 km. It is possible that the water-cluster ion concentrations could have increased steeply to become predominant by 76 or 75 km. In any case, the water cluster ions were suppressed at least over the 9 km range between 77 and 86 km.

The aeronomical implications of these measurements are discussed by Narcisi (these proceedings).

Acknowledgments

This research was supported in part by the Defense Nuclear Agency.

References

Bailey, A.D., Narcisi, R.S. (1966) Miniature Mass Spectrometers for Upper Atmosphere Composition Measurements, Instr. Paper No. 95, AFCRL 66-148.

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

Narcisi, R.S., and Bailey, A.D. (1965) Mass spectrometric measurements of positive ions at altitudes from 64 to 112 km, J.Geophys.Res. 70:3687.

Narcisi, R.S. (1970) Shock wave and electric field effects in D region water cluster ion measurements, Trans.Amer.Geophys.Union 51:366.

Narcisi, R.S., and Roth, W. (1970) The formation of cluster ions in laboratory sources and in the ionosphere, Adv.Electronics Electron Phys. 29:79.

Narcisi, R.S. (1971) Composition studies of the lower ionosphere, chapter in Upper Atmos.Phys. F. Verniani, ed., Casa Editrice Compositori, p.12-59.

Narcisi, R.S., Bailey, A.D., Wlodyka, L.E., and Philbrick, C.R. (1972) Ion composition measurements in the lower ionosphere during the November 1966 and March 1970 solar eclipses, J.Atmos.Terr.Phys. 32:663.

Narcisi, R.S. (1972) Aeronomical implications from ion composition measurements during a PCA (these proceedings).

Ulwick, J.C. (1972) Comparison of Black Brant rocket measurements of charged particle densities during solar particle events (these proceedings).