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F-REGION ION COMPOSITION MODELING

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ABSTRACT

Measurements of the principal ion species of the F_1- and F_2- regions have been used to develop an empirical model of the ion composition for altitudes between 150 and 500 km. The species measured by the S3-1 satellite included N^+, O^+, N_2^+, NO^+ and O_2^+. The data were obtained near the minimum of the solar cycle, thus limited information on the ionospheric variation with solar flux is available. However, the range of latitude, altitude, local time and geomagnetic activity does provide a useful basis for modeling the F-region. The ion composition measurements have been used to provide a model for relative ion composition which is compatible with the total ion density from the International Reference Ionosphere model.

INTRODUCTION

During the period of November 1974 through May 1975, the mass spectrometer on the S3-1 satellite collected data on the density of the five principal ion species in the F-region [1]. Measurements from about 1900 orbits covering the altitude range from 150 to 500 km have been used for development of an empirically based model of the ionospheric behavior. A comparison of the composition measured by the satellite [2] with the International Reference Ionosphere (IRI) [3] had indicated that the ion composition modeled by the IRI could be improved by using a broader data base. The ion composition which was included in the IRI had been based primarily on the summary of the rocket measurements which had been prepared by Danilov and Semenov [4]. This summary adequately represented the E- and lower F-region measurements for the approximately 42 rocket flights which were then available. However, the data collected by one satellite experiment, such as the S3-1, provides a much better data base from which to derive statistically significant modeling parameters. The ion density and composition measurements from the S3-1 satellite and the AEROS-B satellite have been compared [2,5] and the results have shown excellent agreement. The laboratory calibration of the S3-1 experiment was refined by a study which compared the S3-1 summed ion density to the critical frequency measured by ground based ionosondes. The comparisons were made in 73 cases where the satellite passed through the F_2 peak within ± 15 minutes and within ± 5° longitude/latitude of the ionosonde measurement. The progress on the development of the F-region model and some comparisons to the IRI have been reported [6]. One of the points recognized in those comparisons was that the shape of the IRI density profile on the bottom side of the F-region was different from the profile empirically modeled. However, the purpose of this paper is to report on the ion composition modeling and to propose modifications to the model of the F-region composition within the framework of the IRI.

MODELING APPROACH

The measurements for each of the ion species and for the total density have been divided into data bins with the ranges of altitude, solar zenith angle, and latitude shown in Table I. Many other choices for the subdivision of the data could have been attempted. This selection, however, permits the general features of the ionosphere to be examined. The bins which contained too few points were not considered in order to remove bias from the analysis. The number of independent measurements in each bin ranged from a few tens to several hundreds. In Figure 1 the altitude profiles resulting from the mean of each data bin are plotted for two conditions. The number of measurements in each data bin is sufficiently large that a smooth profile results, no altitude smoothing was performed. These two cases show the density and composition for the mid-latitude extremes between winter nighttime and summer day time conditions. The IRI [3] and Bent [7] ionospheric models are shown for comparison. Several interesting comparisons can be made between the S3 model of the total ion density and the IRI model, however, the relative ion composition results will be the main focus of this paper.

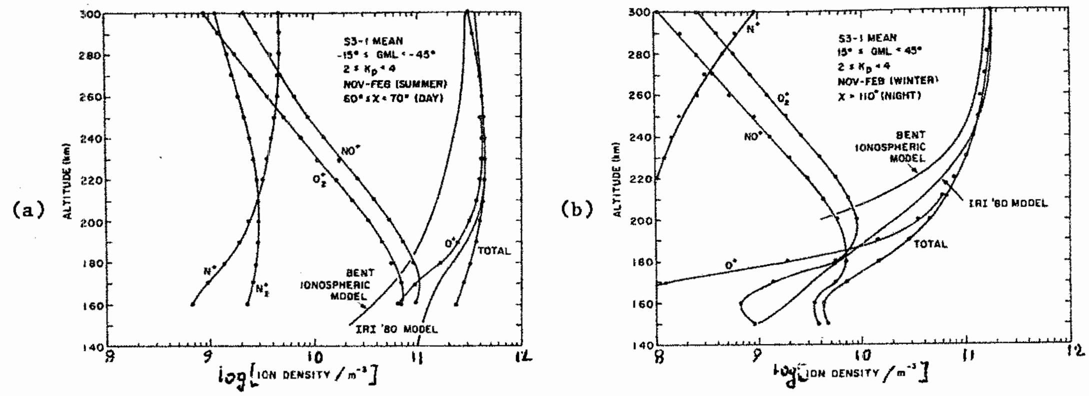

Fig. 1. The mean ion species and total density profiles are shown for midlatitude summer daytime and winter nighttime conditions together with the appropriate profile for total ion density from the IRI and Bent models.

In Figure 2 the latitude variation of the O^+ density at 300 km and 180 km is shown for 5° intervals of geomagnetic latitude. This example shows that there are significant variations in smaller latitude intervals than that chosen for the modeling study. The larger variations are in the F_1-region at night when the density is strongly controlled by local production in specific geomagnetic latitude regions. The examination of results such as this were considered in choosing the latitude regions for the composition model. Figure 3 shows the relative ion composition comparisons for the solar zenith angle dependence at 190 km for mid-latitude summer and winter conditions. This dependence is particularly interesting because the crossover between atomic and molecular ion species predominance occurs in this altitude region. In Figure 4 the solar zenith angle dependence for NO^+ and O^+ is shown at several altitudes for winter, mid-latitude conditions.

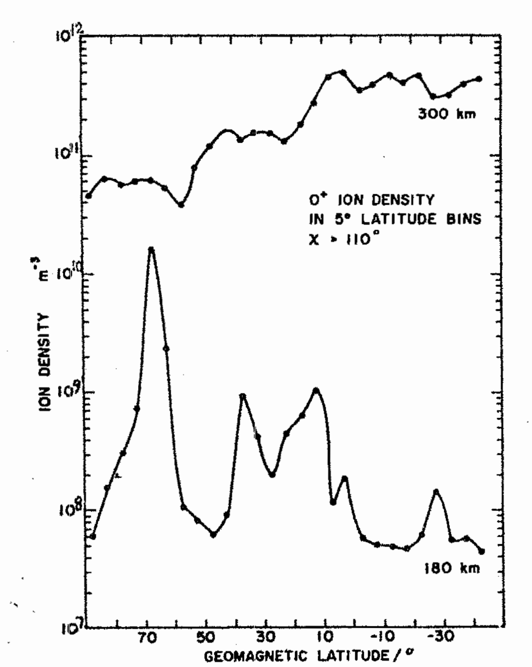

Fig. 2. The latitude profiles of the mean O^+ density are shown for altitudes of 300 and 180 km.

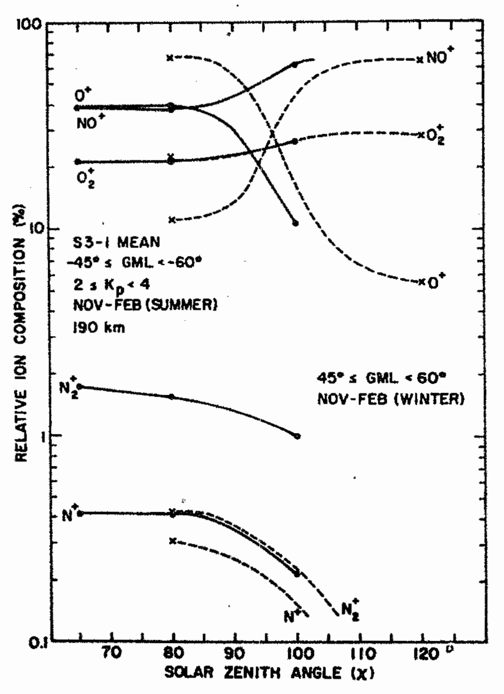

Fig. 3. The midlatitude summer and winter mean variations of ion composition are shown as a function of solar zenith angle.

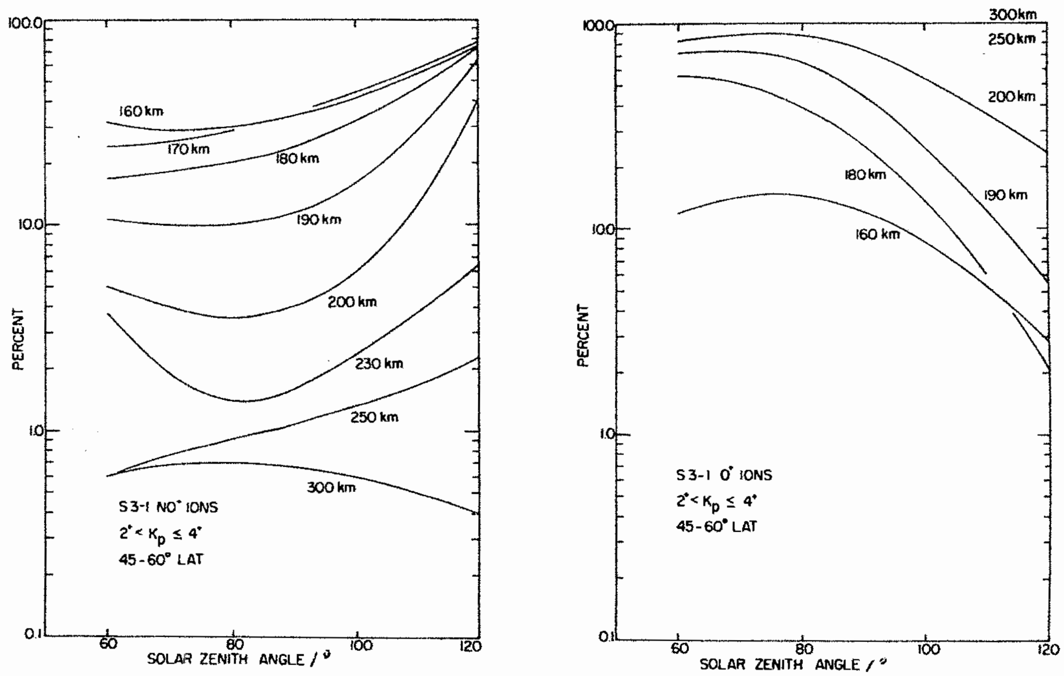

Fig. 4. The dependence of the relative ion variations of NO^+ and O^+ on solar zenith angle is shown for midlatitudes for several altitudes.

In Figure 5, four examples of the relative ion composition profiles are presented for the lower altitude region, between 150 and 290 km. Comparison between Figures 5a and b shows the difference between daylit summer and nighttime winter conditions at mid-latitude. A similar comparison for high latitudes is made in Figures 5c and d. Several conclusions can be made based on these comparisons.

(1) The profiles of the molecular ions, NO^+ and O_2^+, follow each other at a nearly constant ratio above 200 km.

(2) Above 200 km, the O_2^+ exceeds the NO^+ at night (winter), while the opposite is true in the day (summer). From these curves alone the distinction between a seasonal and local time phenomena cannot be drawn, however, comparisons of other cases show that the effect is primarily related to the solar angle.

(3) The concentrations of N^+ and N_2^+ are strongly related to solar zenith angle. The N_2^+ is only present at F_2-region altitudes during the daylit hours or in the nighttime auroral zone because of the high loss rate by ion electron recombination and charge transfer reactions.

(4) The O^+ contributes more than 80% of the ion density from 250 km to altitudes above 500 km where He^+ and H^+ become important.

(5) The cross-over between the dominance of molecular ions, NO^+ and O_2^+, to that of atomic ions, O^+, occurs normally between 170 and 200 km depending on the geophysical conditions. However, at times of enhanced geomagnetic activity, this cross-over has been observed as high as 400 km.

(6) During the daylit hours, the N^+ density profile follows the O^+ profile at a level of about 1/2 to 2%. At night, the N^+ density becomes insignificant below 200 km because of the absence of significant production sources to offset the presence of chemical losses in the F_1-region.

(7) Below 170 km, the NO^+ becomes the dominant ion species under all of the mean profile conditions.

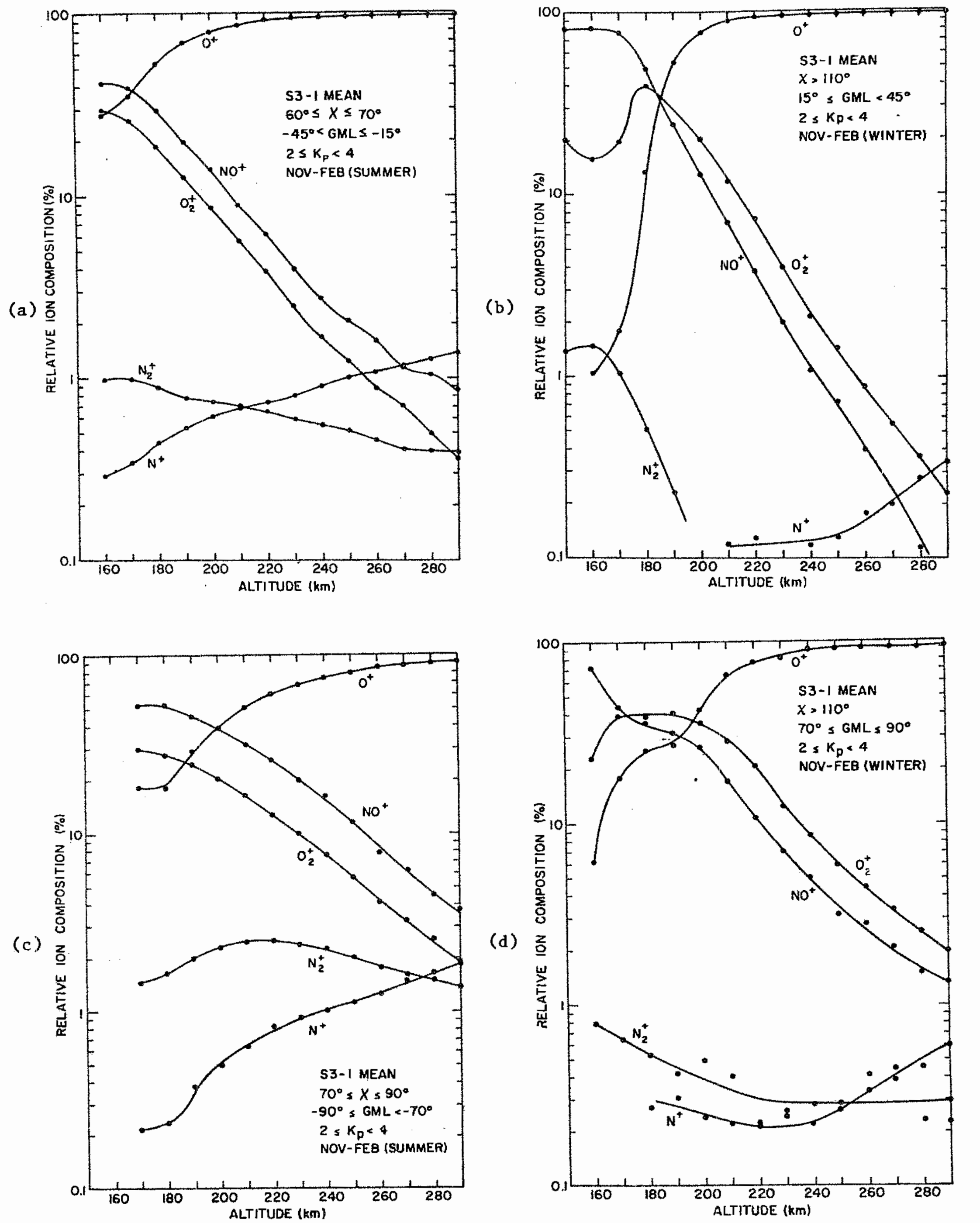

Fig. 5. Relative ion composition percentages are shown for the F_1 and lower F_2 regions for the five species measured by the S3-1 satellite for four cases, (a) midlatitude, day, summer; (b) midlatitude, night, winter; (c) high-latitude, day summer; (d) high-latitude, night, winter.

The data base which has been assembled for the S3-1 mass spectrometer measurements has been used to develop a mean representation of the ion composition. A simplified parameterization of the ion composition has been developed which can be used as a subroutine to the IRI model. This subroutine will generate ion composition which is a reasonable representation of the mean for the S3-1 measurements. It includes interpolation for those cases which were not measured so that results can be obtained for any model condition. This subroutine should provide a more useful model representation for the ion composition. However, it should be used with some caution based on a realization of the limitations of the data on which it was based. The subroutine will be made available to WDC-A for distribution to interested users of the IRI model.

TABLE 1 The Ranges of the Data Bins Used to Construct the Mean Ion Density Values

Altitude(km)		Solar Zenith Angle		Latitude(geomagnetic)		Species	
1	150-160	0	<60°	1	-90° to -70°	1	N^+
2	160-170	1	60°-70°	2	-70° to -60°	2	O^+
:	:	2	70°-90°	3	-60° to -45°	3	N_2^+
14	280-290	3	90°-110°	4	-45° to -15°	4	NO^+
15	290-310	4	>110°	5	-15° to 0°	5	O_2^+
16	310-330			6	0° to +15°	6	Σn_i^+
:	:			7	+15° to +45°		
25	490-510			8	+45° to +60°		
				9	+60° to +70°		
				10	+70° to +90°		

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