Paper 7.1.9. presented at
Workshop on Experience with and Proposed Improvements of the International Reference Ionosphere (IRI), Budapest, Hungary, 11-13 June 1980

Comparison between Plasma Densities Measured with the AEROS-B and S3-1 Satellites and the IRI Model

C.R. Philbrick
Air Force Geophysics Laboratory, Hanscom AFB, Mass., USA

P. Lämmerzahl
Max-Planck-Institut f. Kernphysik, Heidelberg, F.R. Germany

E. Neske and A. Dumbs
Fraunhofer-Institut f. Physikalische Meßtechnik, Freiburg, F.R. Germany

To be published in special WDC-A report on the ionosphere

Abstract

Measurements by a mass spectrometer on S3-1 have been compared with those from an impedance probe and from a retarding potential analyzer on AEROS-B to investigate the relationship of the instruments' response to ionospheric total and partial densities. Conversion of the mass spectrometer data into absolute ion densities is based on a large number of correlated ionosonde observations of the f_0F2 critical frequency. Results of the two different probes on AEROS-B were extensively intercompared and the impedance probe is considered to provide very accurate electron density. The perigees of the two satellites were both over the northern polar region in November 1974 and many crossings at the same latitude and longitude occurred. Among these crossings, five cases were located which meet restrictive conditions minimizing the effects of spatial and temporal variability. The ratio of the densities measured when the two satellites were closest to these crossing points exhibits a mean of 1.00 with 6% standard deviation, and the relative composition of molecular and atomic ions agrees within about 20%. Density variations were found to be correlated with invariant magnetic latitude rather than to strongly depend on altitude, in the F-region. Data are compared to the International Reference Ionosphere model values for density and ion composition in the F-region.

1. Introduction

The basic properties of the ionospheric plasma such as density, temperature, and composition have been investigated by many different probing techniques using ground-based sounding facilities as well as satellite and rocket-borne instrumentation. Various efforts to cross-check such measurements for a better estimate of their reliability and accuracy have been reported (Taylor and Wrenn, 1972; Roble et al., 1978).

In-orbit intercalibration is particularly important to ion mass spectrometers for determining their absolute sensitivity to ambient total ion number densities. A reliable calibration cannot be achieved in a laboratory experiment, due to the inherent difficulties in simulating the ion flow conditions to an instrument on an orbiting spacecraft. Any effects of discrimination between different masses that the analyzer may produce are evaluated in the laboratory and taken into account in analysis of the data. The factor for converting ion currents into number densities, however, is usually derived from normalizing the summed currents of all ion masses to the total plasma density as obtained from some other experiment. If such an experiment were included on the same satellite or rocket, then in-flight calibration of an ion mass spectrometer would be straightforward (Hoffman et al., 1973, 1974). The variability of the ionosphere, however, makes it difficult to find comparisons of measurements from different satellites or between a satellite and ground-based ionosonde or incoherent scatter radar observations which are sufficiently close to be correlated.

An ion mass spectrometer which collected a large number of ion composition measurements in the altitude range between 150 km and 500 km was onboard the S3-1 satellite. Five sets of measurements were located where this satellite passed very near the AEROS-B satellite which, among other experiments, carried an impedance probe and a retarding potential analyzer. At the crossings, both satellites were passing the same latitude and longitude within a few minutes and at altitude separations small compared to the plasma scale height. Five cases meet rather restrictive conditions to minimize the effects of spatial and temporal variability, which allowed a direct intercomparison between the density and ion composition measurements from these satellites. Excellent agreement was found between absolute number densities and percentage composition which gives additional confidence in the accuracy of both data sets.

The orbital plane of the AEROS-B satellite corresponded to local times near 0400 and 1600 and that of the S3-1 to times near 1100 and 2300. The time difference between the orbit planes means that crossings will only occur at high latitude and for these cases the crossings are near 79°N. At this high latitude, the ionospheric plasma is often highly irregular and it has been found that comparisons in terms of invariant latitude appear to be more important than do altitude differences of tens of kilometers in the 250 km to 400 km altitude range.

The importance of reliable plasma measurements for establishing empirical reference models of the ionosphere is obvious. Analysis of data obtained from AEROS has shown that the ionospheric global behaviour as described by the current CCIR numerical map (CCIR Report 340, 1967) needs to be corrected (Noor Sheikh et al., 1978), in particular, to account for longitudinal effects in the equatorial region that are stronger than predicted (Neske et al., 1980; Lämmerzahl et al, 1979b). The

AEROS data base has also been incorporated in the International Reference Ionosphere (IRI) by Rawer et al. (1978) and Rawer (1980). The S3-1 ion data represent a unique set of lower and upper F-region composition measurements of almost complete global coverage which are excellently suited for modelling the ionospheric composition pattern. Comparisons with the IRI both for single observations and on a statistical basis demonstrate a need for further improvement in ionospheric modelling. A few of these results are presented.

2. The Experiments

This study is based on measurements obtained from a mass spectrometer (ion composition) on the S3-1 satellite, and from an impedance probe (electron density) and a retarding potential analyzer (densities of major ions) on the AEROS-B satellite. The AEROS experiments have been described by Neske and Kist (1974) and by Spenner and Dumbs (1974), respectively. The mass spectrometer was of similar design as an earlier flown instrument (Philbrick, 1974). Further details on the three experiments and data evaluation procedures are published elsewhere (Philbrick et al., 1980).

AEROS was a cooperative German-U.S. aeronomy satellite program designed to obtain simultaneous measurements of the most important properties of the neutral gas and the plasma in the upper atmosphere, together with the flux of ionizing solar radiation in the extreme ultraviolet, in order to investigate the coupling between the atmospheric components and its control by solar energy (Lämmerzahl and Bauer, 1974; Lämmerzahl et al., 1979a). The second of two satellites, AEROS-B, was launched in July 1974 and provided measurements until September 1975 when it reentered the atmosphere.

In-situ electron density data was obtained on AEROS-B by a r.f. impedance probe (IP) designed to measure the modified upper hybrid resonance frequency. This frequency is directly related to the electron density of the ambient plasma in a rather large sensitive volume as determined by the 180 cm length of the sensor. During each cycle of six data points at one second intervals the resonance phase conditions and the dc-bias voltage were altered for diagnosis of the plasma interaction on the probe. The effect of an ion sheath on the measured density was shown to be negligible, and a spread in the densities of 4%, in the mean, is observed over a cycle. The high degree of internal consistency gives confidence in the reliability of this technique. The accuracy of the absolute values of the electron density is generally better than 10%, and for the densities considered in this paper, generally greater than $10^5 cm^{-3}$, the accuracy should be near 5%.

The ion mode of the retarding potential analyzer (RPA) on AEROS-B provided the temperature and densities of the major ions every 18 seconds, corresponding to a 140 km spatial resolution. The sensor was of planar geometry and the scan period of 1 second was synchronized with the spin phase to provide measurements at angles within $\pm 30^0$ of ram. The measured current-voltage curve was analyzed in a fitting procedure by varying the assumed four constituent densities (H^+= mass 1, He^+ = mass 4, O^+= mass 16, and molecular ions = mean mass 31), the temperature , and the spacecraft potential, as free parameters. When the residuals became too large the results were rejected. The total ion density has been compared with the electron density from the impedance probe on the same satellite. A difference of 20-30% by which the RPA values are systematically lower than the IP data is explained as due to a transmission loss in the RPA grid assembly for ion flow, and the partial densities from the RPA must be corrected by a corresponding common factor. This correction has not been made in the results presented.

The S3-1 was the first in a series of three satellites designed to provide a scientific study of the properties of the upper atmosphere and to emphasize investigations of the coupling between the neutral atmosphere and the ionosphere over the altitude range between 150 and 500 km. The near polar orbit was highly eccentric with perigee near 150 km and initial apogee near 4000 km. During the period from early November 1974 through May 1975 low altitude data were obtained that cover almost all latitudes and four ranges of local time, near 1100, 2200, 0700, and 1700. Among the several experiments carried on the satellite was a mass spectrometer which measured both the neutral atmosphere and ionosphere species densities. The five ion masses it was tuned to measure were N^+, O^+, N_2^+, NO^+, and O_2^+.

Calibrations with various gas mixtures showed that the mass discrimination of the quadrupole was less than 5% over the mass range. The conversion of the collected ion currents into absolute density was derived from a comparison of flight data with ground-based ionosonde data. A total of 74 cases were identified where good correlation between ionosonde observations from a worldwide distribution of stations and the satellite measurements should exist. The criteria applied to select these cases was that the satellite should be at the F_2 peak, as determined by the satellite altitude profile of summed ion current, and simultaneously be crossing a latitude and longitude box of $5^o \times 5^o$ centered about an ionosonde station, and further that the f_oF_2 critical frequency should have been measured within about 15 minutes. The comparison between the f_oF_2 determined electron density and the summed ion current yielded the instrument sensitivity to ions. Standard deviation was $\pm 26\%$, and no long term trend of change in sensitivity was detected.
Based on the consideration of the calibrations and the in orbit performance, the ion densities reported should be better than $\pm 15\%$ and the relative composition better than $\pm 10\%$ for densities greater than $10^2 cm^{-3}$.

3. Comparison of Experiments

The ion mass spectrometer (MS) results from the S3-1 satellite have been compared with the impedance probe (IP) and retarding potential analyzer (RPA) results from the AEROS-B satellite (Philbrick et al., 1980). The results of that comparison for five nearly coincident sets of measurements showed excellent agreement for both total density and ion composition. In Figure 1 the measurements obtained near one of the crossings of the S3-1 and AEROS-B satellites are shown. The molecular ion densities (NO^+, N_2^+, O_2^+) from the MS have been summed to compare to the RPA measurements of molecular ions. The O^+ profiles for the RPA and MS instruments and the total ion density (MS) and electron density (IP) are shown for comparison. Arrows indicate the crossing point of the orbits. In Figure 2a and 2b the same orbit intersection is shown but the results are shown versus invariant latitude and the intersection of the orbits is shown in geodetic and corrected geomagnetic coordinates. The invariant latitude display of the data was found to best depict the correlations between the measurements. At these high latitudes the altitude is less important than invariant latitude in describing the density distribution of the F-region ions.

A study of the five cases of comparable results from the two satellites (Philbrick et al., 1980) resulted in a ratio between the AEROS-B and S3-1 total densities of $1.00 \pm .06$ and agreement between the molecular and atomic ion concentrations within about $\pm 20\%$.

4. Comparison of Measurements to IRI Model

In Figure 1 the altitude profiles for electron density and molecular ion density from the IRI model has been included corresponding to the conditions for the intersection of the orbits. The general agreement between the IRI and the measurements is reasonably good considering that the ionospheric variability at these high latitudes is large. Other comparisons of the electron (or total ion) density between the IRI model and MS measurements have been made and generally good agreement has been found near the peak of the F_2-region but some significant differences have been found in the F_1-region.

Figures 3 and 4 display a comparison between the ion composition measurements and the IRI composition. The two cases chosen for comparison represent summer daytime and winter nighttime mid latitude conditions. The latitude, solar zenith angle (χ), and other conditions stated on the figures were chosen to allow the closest comparison between the satellite measurements, the IRI model, and the original rocket data summary of Danilov and Semenov (1978) on which the IRI composition was based. In the summer daytime case, Figure 3, each of the satellite mean profiles represent between 70 and 110 independent measurements per 10 kilometer altitude interval and in the case of Figure 4 between 150 and 250 measurements per 10 km interval. The rocket summary, and hence the IRI model, represent the summary of a total of 43 profiles which had to be distributed by season, solar zenith angle and other parameters. The rocket derived composition summary thus cannot be expected to have the statistical significance which we can now obtain from the satellite data, however, differences are surprisingly large. One may suspect that some of the rocket observations were biased with regard to particular launching conditions or other parameters affecting the ionosphere, whereas satellite data represent a much more random distribution.

We conclude that for constructing improved models of ionospheric composition it is essential to include data from satellites that have become available. The consistency between these data sets from the S3-1 and AEROS-B satellites which has been demonstrated, is an encouraging result for the further developments of ionospheric models.

Acknowledgements

We wish to thank M.E. Gardner , D. Delorey, E.J. Ziemba and H. Wolf for their efforts in the data computations. The helpful discussion and comments by K. Rawer and K.S.W. Champion are appreciated. Data used in connection with this article were obtained from WDC-A for Solar-Terrestrial Physics (Ionosphere). This work was completed while one of us (C.R.P.) was staying at the Max-Planck-Institut für Kernphysik as a visiting scientist. This work has been sponsored in part by the Bundesminister für Forschung und Technologie through DFVLR.

References

C.C.I.R. (Comité Consultatif International des Radiocommunications)	1967 French	Atlas CCIR des caractéristiques ionosphériques, Rapport 340, U.I.T., Geneva
DANILOV, A.D. and V.K. SEMENOV	1978 English	Relative ion composition model at mid-latitudes, *J.Atmos.Terr. Phys.*, 40, 1093.
HOFFMAN, J.H., W.B. HANSON, C.R. LIPPINCOTT, and E.E. FERGUSON	1973 English	The magnetic ion-mass spectrometer on Atmosphere Explorer, *Radio Science*, 8, 315.
HOFFMAN, J.H., W.H. DODSON, C.R. LIPPINCOTT, and H.D. HAMMACK	1974 English	Initial ion composition results from the ISIS 2 satellite, *J.Geophys.Res.*, 79, 4246.
LÄMMERZAHL, P. and S.J. BAUER	1974 English	The AEROS mission, *J.Geophys.*,40, 571.
LÄMMERZAHL, P., K. RAWER, and G. SCHMIDTKE	1979a English	The AEROS satellites: data basis and integrated analysis, *J. Geomag.Geoelectr.*, 31, Suppl., S9.
LÄMMERZAHL, P., K. RAWER, and M. ROEMER	1979b German	Ergebnisse des AEROS-Satellitenprogramms, MPI H-1980-V3, MPI für Kernphysik, Heidelberg.
NESKE, E. and R. KIST	1974 English	Impedance probe. The AEROS-B electron density experiment, *J.Geophys.*, 40, 593.
NESKE, E., K. RAWER, and C. REBSTOCK	1980 English	Longitudinal variation of peak electron density at low latitudes, in *Low Latitude Aeronomical Processes*, COSPAR Symposium Series, vol.8 p. 107.

NOOR SHEIKH, M., E. NESKE, K. RAWER, and C. REBSTOCK	1978 English	Comparison of peak electron densities of the F2 layer derived from in-situ measurements with CCIR predictions, Telecomm. J., 45, 225.
PHILBRICK, C.R.	1974 English	Satellite measurements of neutral atmospheric composition in the altitude range 150 to 450 km, Space Research, XIV, 151,
PHILBRICK, C.R., P. LÄMMERZAHL, E. NESKE, and A. DUMBS	1980 English	Comparison of plasma densities in the daytime polar F-region as measured with the AEROS-B and S3-1 satellites, submitted for publication.
RAWER, K., S. RAMAKRISHNAN, and D. BILITZA	1978 English	International Reference Ionosphere 1978, U.R.S.I., Brussels.
RAWER, K.	1980	Private communication of IRI version as of February 1980 (IRIF07
ROBLE, R.G., A.I. STEWART, M.R. TORR, D.W. RUSCH, and R.H. WAND	1978 English	The calculated and observed ionospheric properties during Atmospheric Explorer-C satellite crossings over Millstone Hill, J.Atmos.Terr.Phys., 40, 21.
SPENNER, K. and A. DUMBS	1974 English	The retarding potential analyzer on AEROS-B, J.Geophys., 40, 585.

TAYLOR, G.N. and G.L. WRENN	1970 English	Comparisons of simultaneous satellite and ground-based measurements of ionospheric parameters, Planet. Space Sci., 18, 1663.
WHALEN, J.A.	1970 English	Auroral oval plotter and nomograph for determining corrected geomagnetic local time, latitude, and longitude for high latitudes in the northern hemisphere, AFCRL-70-0422, Environmental Research Papers, no. 327. NTIS Accession No. AD 713170.

Figure Captions

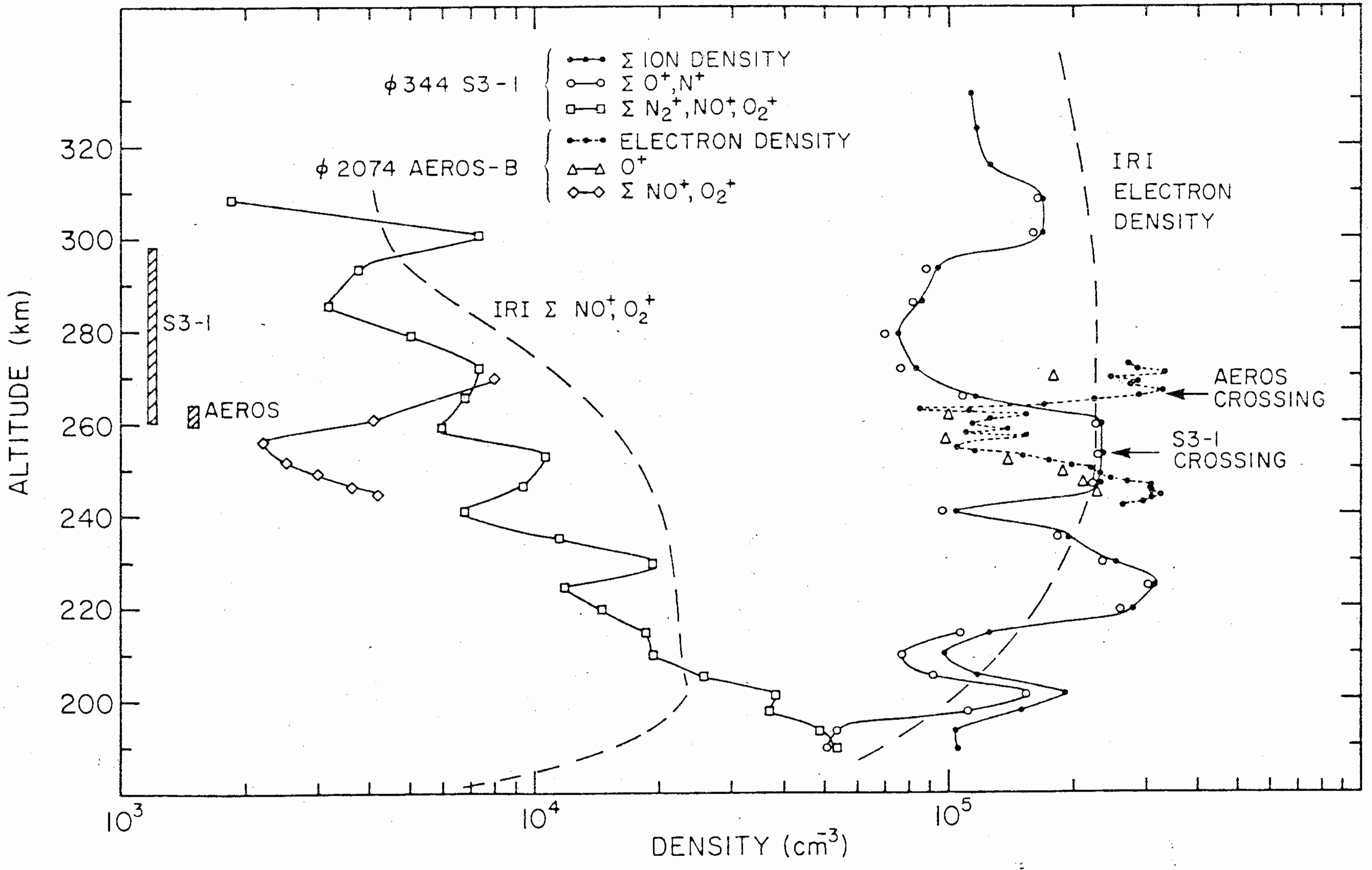
Fig. 1 Total and partial density height profiles from AEROS-B and S3-1 experiments near a crossing of both satellites, within 7 minutes from each other, on 29 November 1974. IRI model densities (using the option for foF2 derived from the equations of Chiu) are shown for comparison. Regions where the satellites passed through the auroral oval are marked by bars. $Kp = 1^+$.

Fig. 2a Comparison of densities from AEROS-B and S3-1 at the same crossing as in Fig. 1, plotted versus invariant magnetic latitude.

Fig. 2b Satellite trajectories near the crossing projected in both geodetic and corrected geomagnetic coordinates. The two broad lines represent the limits of the auroral oval for low geomagnetic activity (Whalen, 1970).

Fig. 3 Summer mid-latitude daylight composition of the lower F-region ionosphere. Mean densities from S3-1 measurements are compared to the IRI model (Rawer, 1980) and the original rocket summary (Danilov and Semenov, 1978).

Fig. 4 Winter mid-latitude nighttime composition of the lower F-region ionosphere.



ALTITUDE (km)
320
300
280
260
240
220
200
DENSITY (cm^{-3})
10^3
10^4
10^5
S3-I
AEROS
ϕ 344 S3-I
Σ ION DENSITY
Σ O^+, N^+
Σ N_2^+, NO^+, O_2^+
ϕ 2074 AEROS-B
ELECTRON DENSITY
O^+
Σ NO^+, O_2^+
IRI Σ NO^+, O_2^+
IRI ELECTRON DENSITY
AEROS CROSSING
S3-I CROSSING

Fig. 1

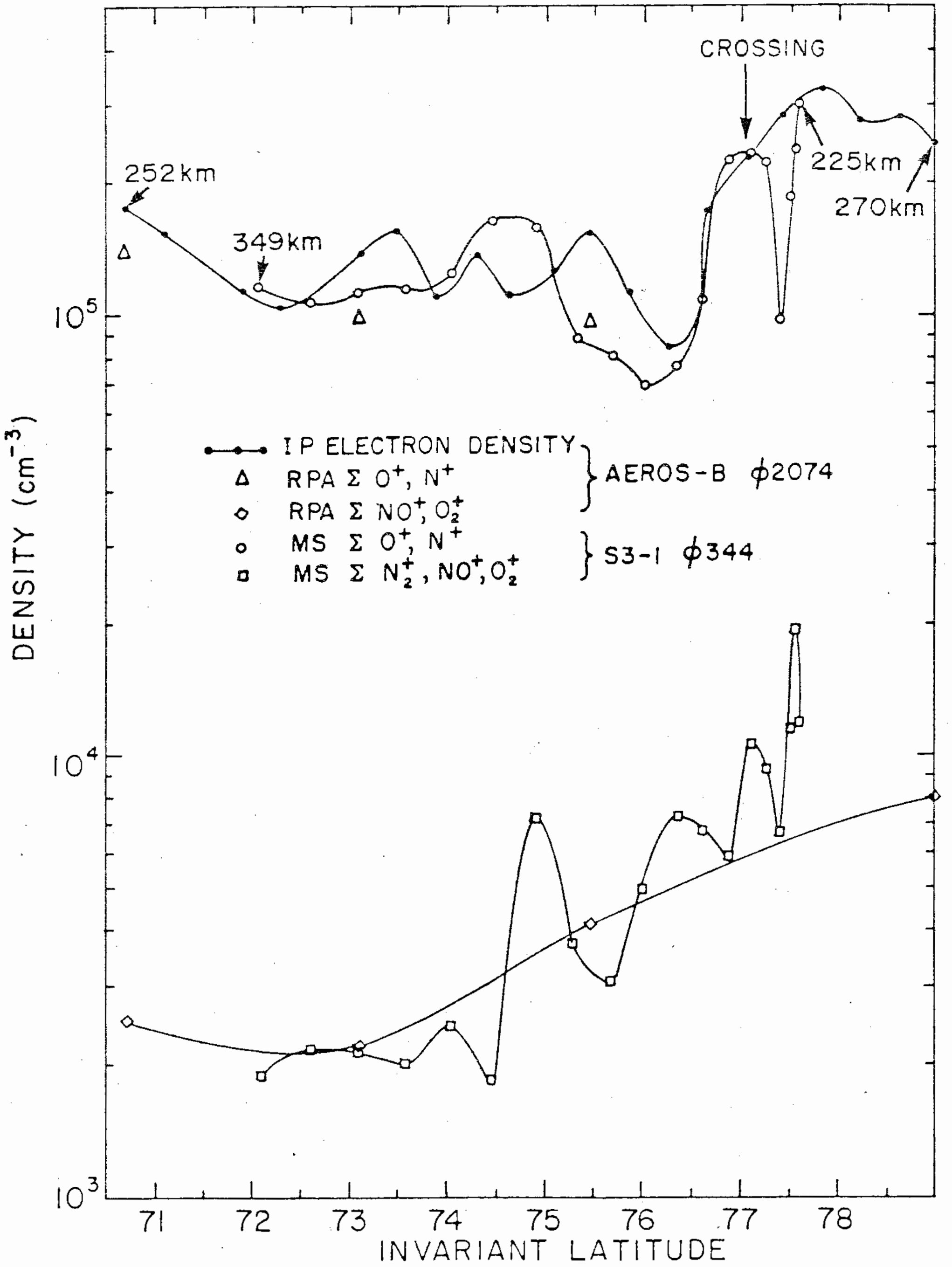

CROSSING
252km
349km
225km
270km
DENSITY (cm^{-3})
10^5
10^4
10^3
71
72
73
74
75
76
77
78
INVARIANT LATITUDE
I P ELECTRON DENSITY
RPA Σ O^+, N^+
RPA Σ NO^+, O_2^+
MS Σ O^+, N^+
MS Σ N_2^+, NO^+, O_2^+
AEROS-B ϕ2074
S3-1 ϕ344

Fig. 2a

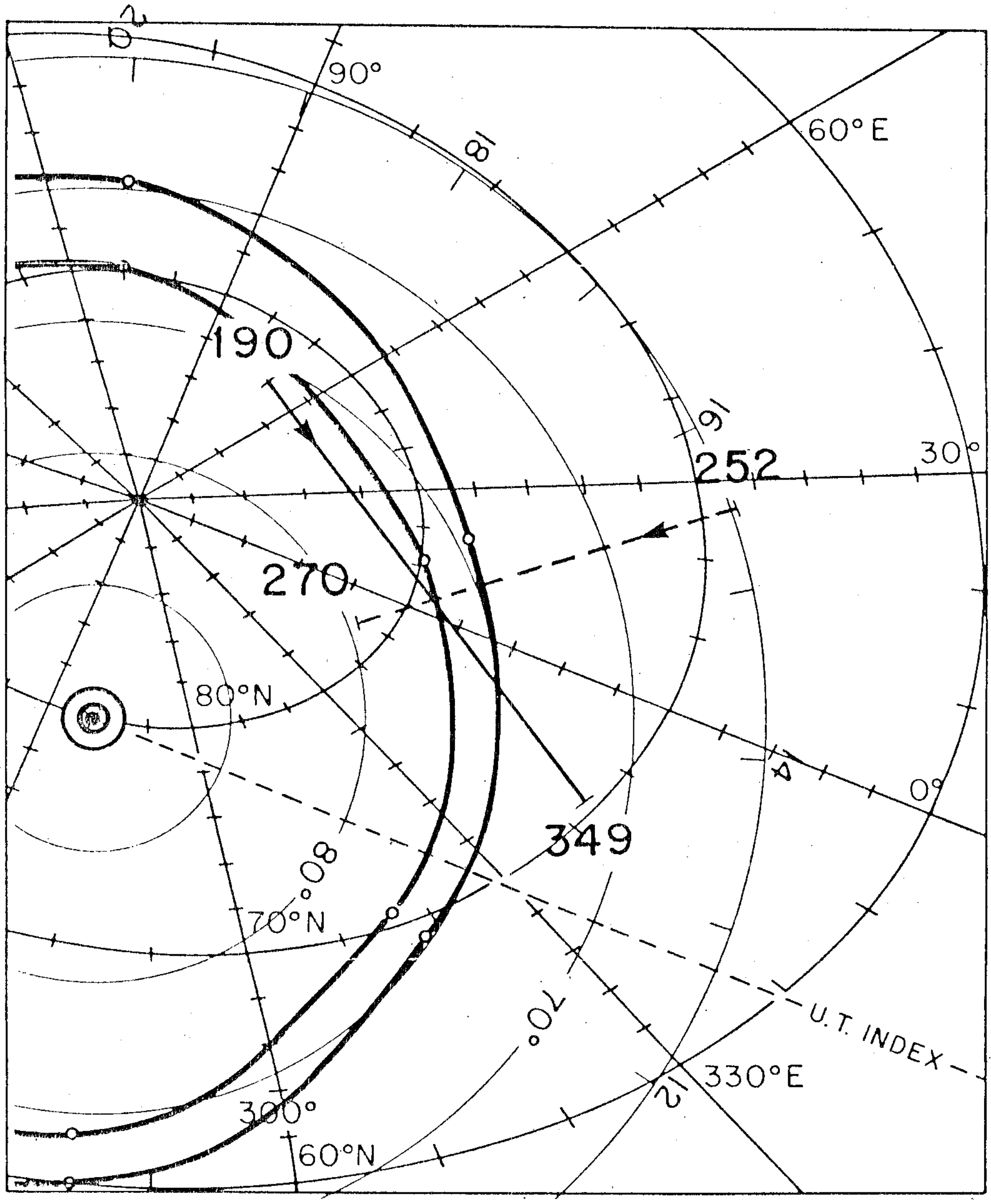

90°
60°E
18
190
16
252
30°
270
80°N
14
0°
349
80°
70°N
70°
U.T. INDEX
330°E
12
300°
60°N

Fig. 2 b

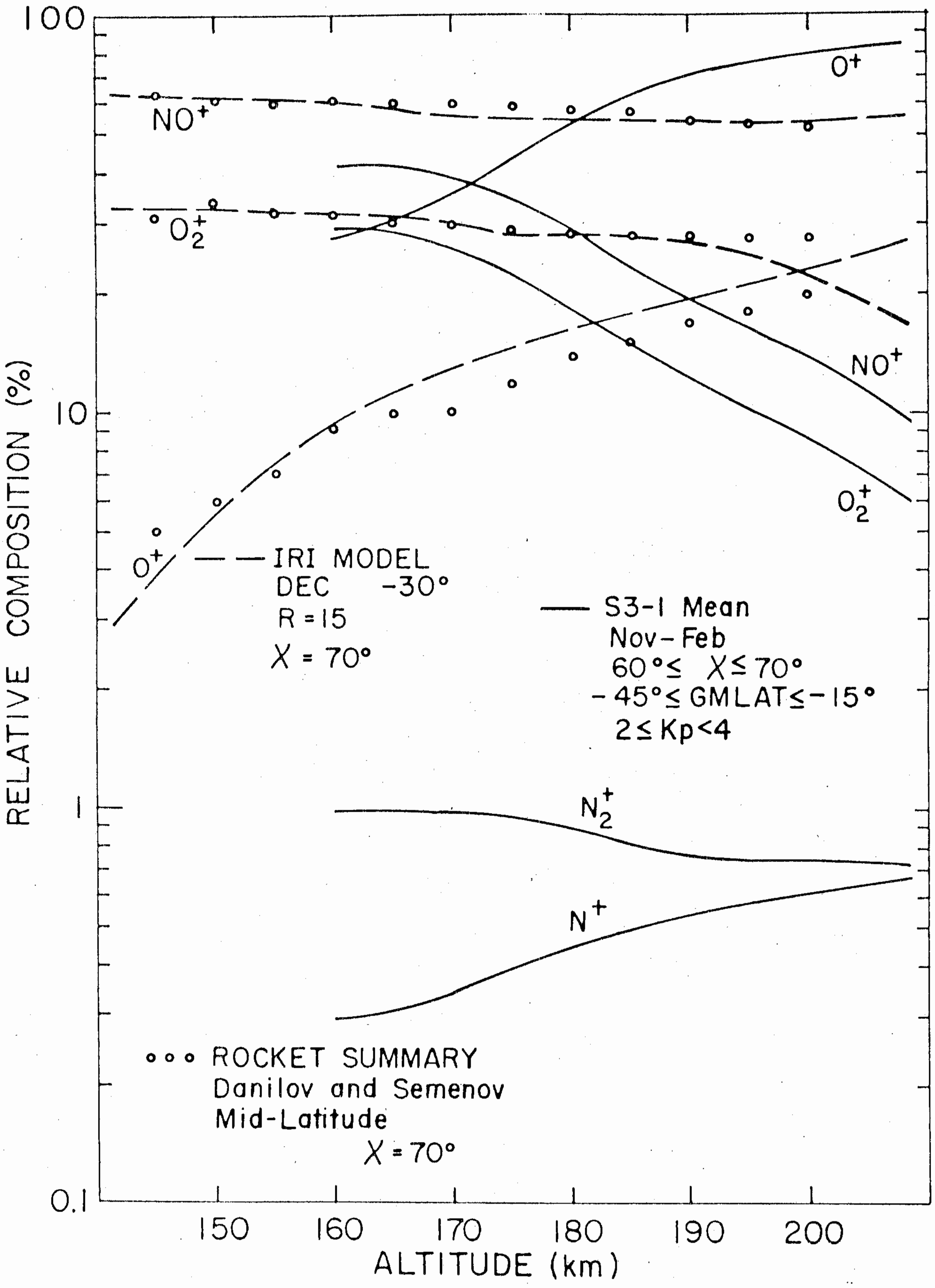

100
10
1
0.1
RELATIVE COMPOSITION (%)
150
160
170
180
190
200
ALTITUDE (km)
O+
NO+
O2+
NO+
NO+
O2+
O2+
O+
N2+
N+
IRI MODEL
DEC -30°
R = 15
X = 70°
S3-1 Mean
Nov-Feb
60° ≤ X ≤ 70°
-45° ≤ GMLAT ≤ -15°
2 ≤ Kp < 4
ROCKET SUMMARY
Danilov and Semenov
Mid-Latitude
X = 70°

Fig. 3

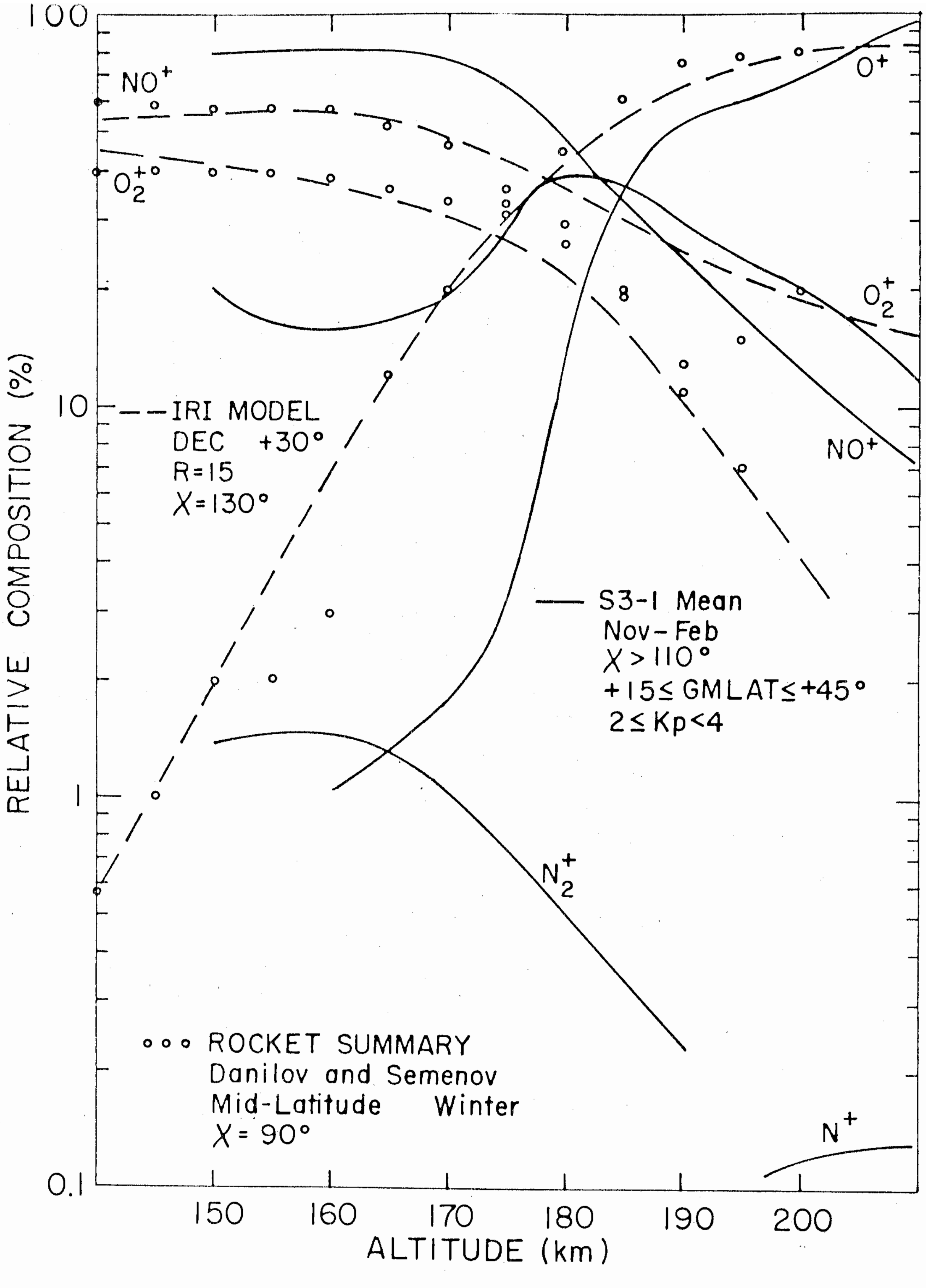

100
10
1
0.1
RELATIVE COMPOSITION (%)
150
160
170
180
190
200
ALTITUDE (km)
NO+
O2+
O+
O2+
NO+
N2+
N+
IRI MODEL
DEC +30°
R=15
χ=130°
S3-1 Mean
Nov-Feb
χ>110°
+15≤GMLAT≤+45°
2≤Kp<4
ROCKET SUMMARY
Danilov and Semenov
Mid-Latitude Winter
χ= 90°

Fig. 4