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Current state-of-the-art for the measurement of non-Maxwellian plasma parameters with the EISCAT UHF Facility

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Abstract. New results on the information that can be extracted from simulated non-Maxwellian incoherent radar spectra are presented. The cases of a pure ionosphere and of a composite ionosphere typical of a given altitude of the auroral F region are considered. In the case of a pure ionosphere of NO^+ or O^+ ions it has been shown that the electron temperature and the electron density can be derived from a Maxwellian analysis of radar spectra measured at aspect angles of 0° or 21° respectively; the ion temperature and ion temperature anisotropy can be derived from a non- constraining model such as the 1D Raman fitting of a complementary measurement made at an aspect angle larger than 0° for the NO^+ ions, or at an aspect angle larger than 21° for the O^+ ions. Moreover with such measurements at large aspect angles, the shape of the velocity ion distribution functions can simultaneously be inferred. The case of a composite ionosphere of atomic O^+ and molecular NO^+ions is a difficult challenge which requires simultaneously a complementary measurement of the electron temperature to provide the ion composition and the electron density from the incoherent radar spectra at a specific aspect angle of 21°; hence, a model dependent routine is necessary to derive the ion temperatures and ion temperature anisotropies. In the case where the electron temperature is not given, a routine which depends on ion distribution models is required first: the better the ion distribution models are, the more accurately derived the plasma parameters will be. In both cases of a composite ionosphere, the 1D Raman fitting can be used to keep a check on the validity of the results provided by the ion distribution model dependent routine.

1 Introduction

Since the first measurement of the O^+ ion temperature anisotropy in the F region in presence of moderate electric field intensity made by Perraut *et al.* (1984) and the first measurement of typical non-Maxwellian spectra made by Lockwood *et al.* (1987), numerous observations of non-equilibrium states were completed at the EISCAT facility. All these observations confirmed the predictions made more than twenty years ago by Schunk and Walker (1972) and by St-Maurice and Schunk (1979): let us note the measurement of the temperature anisotropy by Løvhaug and Flå (1986), Moorcroft and Schlegel (1988), Glattor and Hernandez (1990), Lathuillere *et al.* (1991), McCrea *et al.* (1993); the evidence for non-Maxwellian ion velocity distributions established by Lockwood *et al.* (1989), and Winser *et al.* (1989) among others. Theoreticians also investigated a new generation of more elaborated results such as the works by Hubert (1982a, b, 1983, 1984a, b), Kikuchi *et al.* (1989), Schizgal and Hubert (1989), Barakat and Hubert (1990), Hubert and Barakat (1990), Tereschenko *et al.* (1991), Winkler *et al.* (1992), Kinzelin and Hubert (1992), Hubert and Kinzelin (1992). The motivation for the present work is to take stock of the requirements to extract plasma data from non-Maxwellian incoherent radar spectra, and to propose an effective scenario for measurements as suggested in the letter by Hubert *et al.* (1993).

A very important challenge in the study of auroral non-Maxwellian process in the presence of large electric fields is the measurement of the ionospheric plasma parameters describing the non-equilibrium state (Raman *et al.*, 1981). The 3D Raman fitting has been used by Lockwood and Winser (1988), Suvanto *et al.* (1989a), and Winser *et al.* (1989) but can only be considered as a zero-order approach in the case of a pure ionosphere as shown by Hubert and Kinzelin (1991). In the presence of a mixture of atomic and molecular neutrals, the assumption of the equality of the O^+ ion temperature and of the NO^+ ion temperature which is always made in the 3D Raman fitting is not justified, as shown by Hubert and Kinzelin (1992), and recently confirmed in Monte Carlo simulations by Gaimard (1996). The 1D Raman fitting used for the first time in space science by St-Maurice *et al.* (1976), and extended to radar spectra

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analysis for angle-of-sight from 30° to 90° by Kikuchi *et al.* (1989), seems to be very promising by virtue of its ability to fit any toroidal ion distribution function with only two effective shape parameters. These two fitting models have been used by Lockwood and Winser (1988) for the determination of ion temperature from an EISCAT CP-3-E experiment at 275 altitude, assuming a pure O^+ ionosphere and a given electron temperature. But it is well known that, as large ion drifts give rise to non-Maxwellian distributions, they simultaneously increase the molecular ion content of the F region mainly above an altitude of 200 km. Therefore in auroral conditions it is necessary to simultaneously fit seven independent parameters to analyse one ionic radar spectrum: these are electron density, electron temperature, ion composition and two effective non-Maxwellian shape distortion parameters for both O^+ and NO^+ ion species. Our attempts to fit so many parameters led to ambiguous results. Then, we proposed a scenario in which we took advantage of the necessity to make at least two measurements along different aspect angles to determine the ion temperature anisotropies, as well as specific properties of non-equilibrium ion distribution functions for a particular aspect angle (Hubert *et al.*, 1993). Indeed Hubert *et al.* (1993) showed that the O^+ ion thermal velocity distribution function in the background of a composite neutral atmosphere displays a specific angle $\varphi_m = 21 \pm 1°$ from the magnetic field direction, along which the 1D line-of-sight distribution is Maxwellian while the NO^+ ion distribution for the same angle is not far from a Maxwellian distribution. Therefore a two-Maxwellian fitting routine for the interpretation of radar spectra obtained at an aspect angle of 21° is well adapted, as discussed by Lathuillere and Hubert (1989), and moreover it is a five parameter fitting. It has been shown that for the right ion composition or electron temperature, the exact electron temperature or ion composition is retrieved respectively as well as a good measurement of the major ion line-of-sight temperature. Then, in this scenario a complementary and simultaneous measurement of the electron temperature is needed such as the one provided by the plasma line observation (Hagfors and Lehtinen, 1981) as well as the measurement of the line-of-sight temperature of the O^+ and NO^+ ions for another angle than 21°. In this work we consider successively the case of a pure ionosphere of O^+ or NO^+ ions and the case of a composite ionosphere of atomic O^+ and molecular NO^+ions. Applying the scenario suggested by Hubert *et al.* (1993) for these two cases, we want to know if it is possible to extract all the plasma parameters from incoherent radar spectra without any assumption on the shape of the non-Maxwellian ion distribution, except that it is a toroidal distribution. If not, we want to discuss what plasma parameters are necessary, and how to obtain them; or if it is necessary to consider other constraints such as a given model of the ion thermal velocity distribution for both ions.

The study is organised as follows. In the second section we study successively the case of a pure O^+ atomic or a pure NO^+ molecular ionosphere. In Sect. 3 we consider the composite ionosphere. The new results are discussed in Sec. 4, and a conclusion ends the work.

2 The ionosphere composed of O^+ or NO^+ ions

For this part of the study we consider first an ionosphere of pure O^+ ions in a background of pure atomic neutral oxygen, for which accurate velocity distribution functions have been obtained from a hybrid Monte Carlo and polynomial expansion approach (Hubert and Barakat, 1990; Barakat and Hubert, 1990). The characteristic properties of the 1D line-of-sight distribution can be ordered

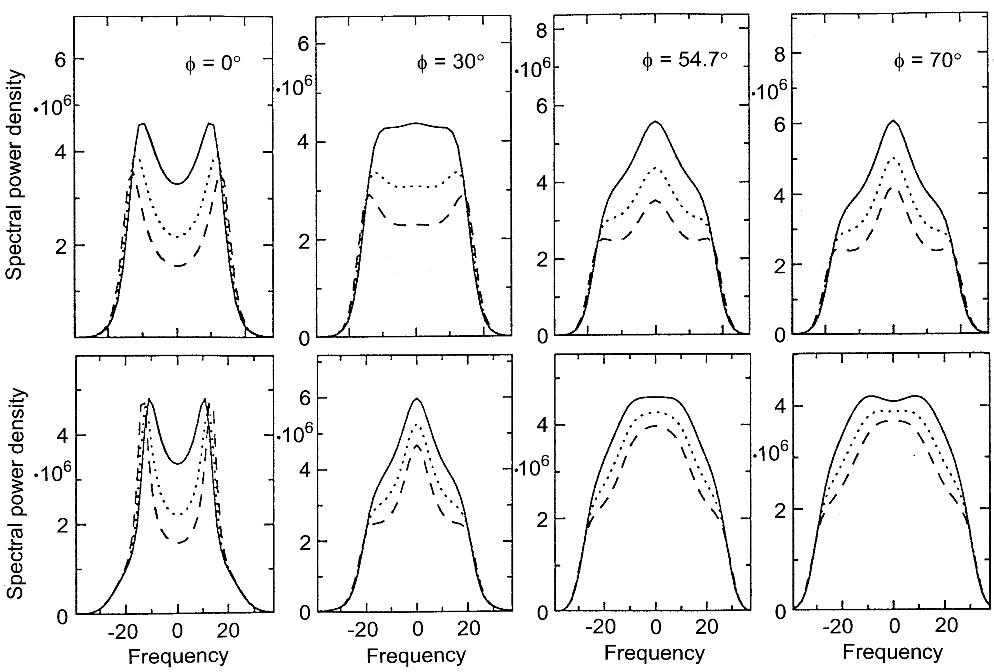

Fig. 1. Atomic O^+ radar spectra for an electric field of 100 mV/m in the *top panels*, and 200 mV/m in the *botton panels.* From the *left* to the *right* the panels correspond to aspect angles $\varphi = 0°$, 30°, 54.7° and 70° respectively. The curves in *solid*, *dotted* and *dashed lines* correspond to electron temperature of 2500, 3500 and 4500 K respectively

with respect to a polar angle φ: along the magnetic field the distribution can be modelled by two Maxwellian distributions at different effective temperatures (Hubert and Leblanc, work in progress), by one Maxwellian at $\varphi_m = 21° \pm 1°$ (Hubert *et al.*, 1993), and by a toroidal 1D Raman distribution implying two shape parameters T^*_φ and D^*_φ for $\varphi > 21°$ (Winkler *et al.*, 1992). The properties of the O^+ distribution are also illustrative of the N_2^+ distribution which could be found in the auroral ionosphere during soft electron events (Farmer *et al.*, 1988; Winkler *et al.*, 1992). In the second part we take into account an ionosphere composed of molecular NO^+ ions.

The consequences of non-Maxwellian ion distributions on the incoherent scattering of radar waves were extensively analysed by Raman *et al.* (1981) who characterized the non-Maxwellian radar spectra for aspect angles larger than 30° for a number of electron to ion temperature ratios. The paper by Hubert and Lathuillere (1989) presented quantitative results for O^+ and NO^+ non-Maxwellian incoherent radar spectra not limited to large aspect angles.

2.1 The O^+ ionosphere case

Figure 1 displays in the top panels the radar spectra for an electric field intensity of 100 mV/m, three electron temperatures of 2500, 3500, 4500 K in solid line, dotted, dashed line respectively, and four aspect angles of 0°, 30°, 54.7°, 70° from the left to the right. These results are very similar to those presented by Hubert and Lathuillere (1989) for an electric field of 100 mV/m. The lower panels display new characteristics when the electric field intensity is 200 mV/m. For an aspect angle of 0° the spectrum shows very pronounced ion acoustic peaks, the central value is very low while the base of the spectrum is broadened; these features are a direct consequence of the core-halo shape of the distribution parallel to the magnetic field. The well-known shape of a non-Maxwellian radar spectrum with a central peak is obtained for an angle as low as 30° for the case of 200 mV/m, but this is no longer the case for 100 mV/m. For an aspect angle of 54.7° and 70° new features are observed, the central peak is transformed into a rounded shape which shows a plateau at the top for an electron temperature of 2500° when $\varphi = 54.7°$, and displays a local trough at the top for $\varphi = 70°$. This localised hole at the top of the central peak is the consequence of the derivative of the ion distribution which is shown to be negative for $\varphi = 70°$ at the origin of the velocities (Hubert and Leblanc, work in progress).

The radar spectra simulated for interpretation take into account the effect of measurement noise corresponding to a typical signal to noise ratio of 0.5, and an integration time of 5 min. For an aspect angle of 0° we have used first a two-Maxwellian routine, i.e. a 5 parameter fit: the electron density noted "n", the electron temperature, two effective temperatures, T_1, T_2 and a pseudo composition $n_1(T_1)/n_2(T_2)$ of Maxwellian populations at temperatures T_1 and T_2 with $n = n_1 + n_2$. This five-parameter fitting does not provide an accurate O^+ parallel temperature, but when the electron temperature is given, we get an

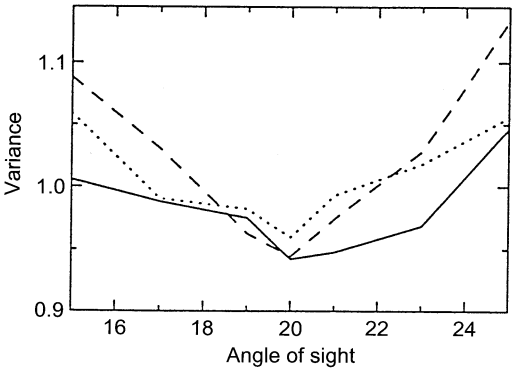

Fig. 2. Evolution of the variance of the fitting for angle-of-sights between 15° and 25° for a Maxwellian fit of O^+ ion spectra when the electric field is 100 mV/m. Three electron temperatures of 2500, 3500 and 4500 K in *solid*, *dotted* and *dashed lines* respectively are considered

accurate O^+ parallel temperature which is within 1% of the exact value for an electric field of 100 mV/m and within 5% for an electric field of 200 mV/m.

For the specific aspect angle of 20° with an electric field of 100 mV/m, the Maxwellian routine provides accurate values of the electron density, of the line-of-sight O^+ temperature, and of the electron temperature. For an electric field of 200 mV/m when $\varphi_m = 21.6°$ we obtain also accurate plasma parameters. To our knowledge a Maxwellian O^+ distribution at a typical angle φ of $21° \pm 1°$ has never been observed. Figure 2 displays the variance of the Maxwellian fitting for angles-of-sight from 15° to 25°, and three electron temperatures for an electric field of 100 mV/m. The best Maxwellian fitting is obtained for $\varphi = 20°$ whether the electron temperature Te is 2500, 3500 or 4500 K. We obtain similar results for a greater electric field intensity. This result could be considered to check the Maxwellian property of the O^+ distribution by a specific geometry of the tristatic EISCAT facility.

The interpretation of radar spectra at an aspect angle larger than 21° has been made using a 1D Raman model, the formal mathematical expression of which is

$$g_\varphi(u') = \frac{2}{\pi} \int_{-\infty}^{+\infty} dr' \exp\left(-D^{*2}_\varphi - (r'^2 + u'^2)\right) \times I_O\left(2D^*_\varphi\, (r'^2 + u'^2)^{1/2}\right), \quad (1)$$

where $u' = u/(2kT^*_\varphi/m_i)^{1/2}$, k is the Boltzmann constant, m_i the ion mass and T^*_φ, D^*_φ are shape parameters (Kikuchi *et al.*, 1989). From this model of distribution we obtain the line-of-sight temperature as given by

$$T_\varphi T^*_\varphi(1 + D^{*2}_\varphi). \quad (2)$$

This fitting process contains four parameters: the electron density, the electron temperature and two effective parameters T^*_φ, D^*_φ. Table 1 presents, for an electric field intensity of 100 mV/m, the output results of the electron temperature, and the ratio of the fitted line-of-sight O^+ temperature to the exact O^+ line-of-sight temperatures for φ from 20° to 80°. As the input electron

Table 1. The aspect angles with the respective fitting parameters, T^*_φ, D^*_φ; the derived electron temperatures and the ratio of the derived line-of-sight O^+ ion temperatures with respect to the exact ones

φ	T^*_φ	D^*_φ	Te	T_φ/T_φ(exact)
20	1732	0.43	3530	1.01
30	1352	0.88	3565	1.01
40	1314	1.09	3479	0.99
50	1366	1.21	3385	0.98
60	1447	1.31	3222	0.95
70	1481	1.38	3167	0.95
80	1465	1.41	3321	0.99

temperature was 3500 K we conclude that the 1D Raman fitting works well for angles-of-sight between 20° and 60°, providing accurate electron temperature as well as O^+ line-of-sight temperatures, except for φ in the region 60°–80°. When the electric field increases to 200 mV/m the four parameters 1D Raman model does not work well.

In one other run we have considered the electron temperature as given. Then the 1D Raman's fitting becomes a 3 parameter fit: the line-of-sight output ion temperatures accurately compare to the correct ones, whatever the angle-of-sight larger than 20° and the electric field intensity.

2.2 *The NO^+ ionosphere case*

The probability that the ionosphere between 150 and 200 km in altitude should be composed by nearly 100% of molecular NO^+ and O_2^+ ions is very large when the electric field intensity increases above 50 mV/m. In this case, the molecular ion distribution is obtained from the generalised solution of Boltzmann's equation extended to a composite neutral atmosphere (Hubert *et al.*, 1993). The expansion obtained at the fourth order in the velocity moments, is accurately defined for electric field intensities as large as 150 mV/m as discussed by Barakat and Hubert (1990).

The 1D Raman distribution as a four-parameter fitting of simulated NO^+ radar spectra provides accurate electron density, electron temperature and line-of-sight ion temperatures, whatever the aspect angle and the electric field intensity. Indeed the ion temperatures obtained are within 1% of the exact values while the electron temperature is within 3%.

Another very interesting output of the 1D Raman fitting is the shape parameter D^*_φ which indicates the degree of distortion of the line-of-sight distribution with respect to a Maxwellian. Figure 3 shows how this shape parameter evolves in terms of the electric field intensity and of the aspect angle, from 30° to 90°. The curve corresponding to 90° is that of the perpendicular component of the ion distribution to the magnetic field which has been shown by Hubert (1983) to mimic the spacecraft observations by St-Maurice *et al.* (1976). The characteristic property of D^*_{90} is to become saturate of for large electric field intensities, like the other shape parameters D^*_φ for $30° \leq \varphi <$ 90°. The parameters D^*_φ also increase with an increasing φ whatever the electric field intensity.

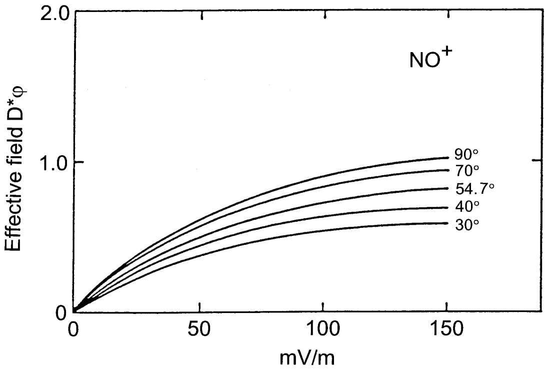

Fig. 3. Shape parameters D^*_φ of the NO^+ line-of-sight velocity distribution as a function of the electric field intensity. All *curves* saturate for all angles φ

3 The composite ionosphere

In a recent study of the measurement of non-Maxwellian plasma parameters, Hubert *et al.* (1993) have shown all the information that can be extracted from the incoherent radar spectra obtained at the specific aspect angle of 21° where the O^+ ion distribution is Maxwellian, and the NO^+ ion distribution not far from Maxwellian. An interesting result is that when the electron temperature is known, the correct ion composition is retrieved, as well as a good measurement of the major ion line-of-sight temperature at 21°. Therefore, complementary measurements are necessary.

Taking into account the shape of the O^+ ion distribution as well as of the NO^+ ion distribution along the magnetic field line, we have considered a three Maxwellian fitting of simulated spectra. Even in the case where the electron temperature is given as well as the O^+/NO^+ composition, we obtain rather poor precision on the parallel temperature of the O^+ population, as well as on the parallel temperature of the NO^+ population. These results are not accurate enough to be useful in the ion temperature or ion temperature anisotropy determination, with use of the complementary measurements made at the aspect angle of 21° or at larger angles.

For aspect angles larger than 21° where both O^+ and NO^+ ion distribution functions are of toroidal shape, we have considered a fitting derived from the addition of two 1D Raman models given by Eq. (1). This analysis fits four shape parameters $T^*_\varphi(O^+)$, $D^*_\varphi(O^+)$, $T^*_\varphi(NO^+)$, $D^*_\varphi(NO^+)$ when the electron temperature and the ion composition are given, but fails to provide relevant parameters to determine the O^+ and the NO^+ line-of-sight temperatures.

The application of a 1-D Raman model for a composite ionosphere fits very well the sum of the two O^+ and NO^+ non-Maxwellian distributions as seen in the Fig. 4 for the case of an electric field of 100 mV/m, and for aspect angles

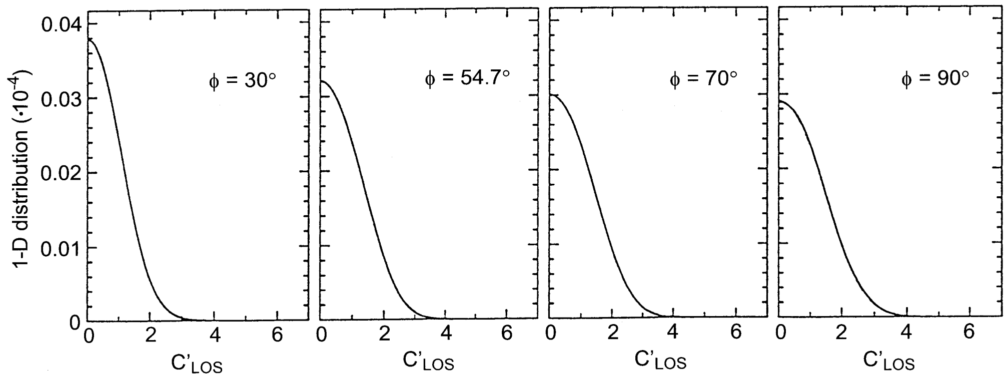

Fig. 4. Results of the 1D Raman's fitting of 1D line-of-sight ion distribution functions for a composite ionosphere of 50% of O^+ ions, of 50% of NO^+ ions and for an electric field intensity of 100 mV/m. The fitting curves with *dashed lines* are indistinguishable from the original curves in *solid lines*

$\varphi \geq 30°$; indeed the original curves and the fitting curves are indistinguishable. This fitting runs on with two shape parameters T^*_φ, D^*_φ and we are moreover forced to choose a mean ion mass M. We have noted that the fitting process is better with use of the O^+ ion mass whatever the ion composition. When we analyse composite radar spectra, the electron temperature has to be given in order to obtain significant results from the 1D Raman fitting. Indeed, in this approach we obtain pseudo-temperatures T'_φ in terms of the sum of two line-of-sight temperatures as given by

$$T'_\varphi = c\frac{M}{m_{O^+}}\,T_\varphi(O^+) + (1-c)\frac{M}{m_{O^+}}\,T_\varphi(NO^+), \tag{3}$$

where c is the O^+/NO^+ density composition, while m^+_O, m_{NO+} are the O^+ and NO^+ ion mass respectively. It can be easily shown from the expression of the line-of-sight temperature (Raman *et al.*, 1981):

$$T_\varphi = T_\parallel \cos^2\varphi + T_\perp \sin^2\varphi, \tag{4}$$

that eq. (3) transforms into:

$$T'_\varphi = T'_\parallel \cos^2\varphi + T'_\perp \sin^2\varphi \tag{5}$$

where $T'_\parallel$ and $T'_\perp$ are the parallel and the perpendicular pseudo-temperatures respectively derived from Eqs. (3) and (4). This result means that whatever the number of measurements from different aspect angles φ_i, the system of equations derived from Eq. (5) will be of rank 2. Then the knowledge of $T'_\parallel$ and $T'_\parallel$ in the system of equations derived from Eq. (3) where we consider $M = m_{O^+}$

$$T'_\parallel = cT_\parallel(O^+) + (1-c)\frac{m_{O^+}}{m_{NO^+}}\,T_\parallel(NO^+),$$

$$T'_\parallel = cT_\perp(O^+) + (1-c)\frac{m_{O^+}}{m_{NO^+}}\,T_\perp(NO^+) \tag{6}$$

does not allow the determination of $T_\parallel(O^+)$, $T_\parallel(NO^+)$, $T_\perp(O^+)$ and $T_\perp(NO^+)$ even with use of a complementary measurement made along the magnetic field line or at $\varphi = 21°$. Indeed, we are left with four unknowns and three equations.

4 Discussion

The measurement of non-equilibrium plasma parameters at a given altitude of the auroral ionosphere from incoherent radar waves has been restricted to two situations: the pure ion composition case, and the composite one. For a pure molecular ionosphere it is possible to obtain the ion line-of-sight temperature, the electron density and the electron temperature whatever the external electric field intensity, and the aspect angle: the 1D Raman fitting works well. Then, from two simultaneous measurements of the same scattering volume at different aspect angles, the ion temperature as well as the ion temperature anisotropy can be deduced directly. The larger the difference between the two aspect angles will be, the better the ion temperature and the ion temperature anisotropy are. But all EISCAT UHF experiments suffer to some degree from the fact that the range of measured angles is not sufficiently large to enable the parallel or perpendicular component of the ion temperature, to be accurately measured, as stressed by McCrea *et al.* (1994) in a deep investigation to improve the design philosophy of EISCAT UHF measurements. For example, in a CP0 experiment at an altitude of 175 km the largest aspect angle at Sodankyla is 35°, so that the field-perpendicular temperature contributed 33% to the line-of-sight temperature. Then the special EISCAT experiment used by Lathuillere *et al.* (1991) to gather evidence about anisotropic temperatures of molecular ions seems to be one of the best compromises as the aspect angle was 29.6° for Sodankyla and 54.7° for Tromsö. The results presented in this paper on the application of the 1D Raman fitting for a molecular ionosphere are dependent on the generalised polynomial solution of Boltzmann's equation proposed by Hubert (1983). However, the results of the Monte Carlo simulations by Winkler *et al.* (1992) support the analytical results for electric field intensities lower than 150 mV/m. One of the predicted properties of the NO^+ distribution is to be Maxwellian in the magnetic field direction, but no observation to our knowledge has yet confirmed this property. The analysis of the variance of a Maxwellian interpretation of radar spectra obtained simultaneously at an aspect angle of 0° and at two other aspect angles as small as possible, but varying from 0°, could confirm this property.

The measurement of O^+ non-Maxwellian plasma parameters is more complicated. One important point is the prediction of a specific angle of $21° \pm 1°$ where the 1-D atomic O^+ distribution should be a Maxwellian. This property could be established by the analysis of the variance of Maxwellian fittings of radar spectra obtained at the aspect angles of 21°, and at two other aspect angles lower and larger than 21°. As soon as the electron temperature is known, the O^+ line-of-sight temperatures for aspect angles larger than 21° are derived whatever the electric field intensity. When the electron temperature is not known, the 1D Raman fitting provides all the plasma data for aspect angles from 21° to 60°, and electric field intensity lower than some 150 mV/m. The probability of the existence of a pure O^+ ionosphere is very low, but the observation of the specific angle of 21° is important for the study of the nature of O^+- O charge exchange process.

In the presence of a composite O^+ and NO^+ionosphere, which is the most probable situation above 200 km in altitude in the F region, for large electric field intensities (Schunk *et al*., 1975) we have shown that:

1. When the electron temperature is given, the ion composition could be derived from measurements made at the typical aspect angle of 21°. For aspect angles larger than 21°, the 1D Raman fitting provides pseudo ion temperatures which can be very important as a constraint compared to the results of the model dependent routine elaborated by Gaimard *et al.* (1996). Moreover the comparison of the ion composition derived from the aspect angle of 21° and of the O^+ and NO^+ line-of-sight temperatures for 21°, to the corresponding quantities obtained from the Gaimard's procedure is a way to check the ion-neutral scattering cross section selected in the given distribution-dependent routine.

2. When the electron temperature is not given by an independent measurement, a model dependent routine seems necessary to extract any information from non-Maxwellian radar spectra. Gaimard's routine is then an effective tool whose virtue is to work with only one spectrum, whatever the aspect angle, and to provide all the plasma parameters. For aspect angles larger than 21°, the 1D Raman fitting also provides pseudo ion temperatures which can be used to check the validity of Gaimard's routine results.

5 Conclusions

The incoherent scatter radar technique for the measurement of ionospheric plasma parameters is very powerful. We have shown that in the case of an ionosphere composed of one ion species, non-Maxwellian incoherent radar spectra contains all the information on plasma parameters which can be extracted from a non-constrained approach. Moreover, it has been shown that the shape of the ion distributions can be measured in a complementary approach to spacecraft observations. The composite ionosphere case requires finally an ion distribution dependent procedure, the validity of which can be compared to the results derived from a non-constrained model when the electron temperature is derived independently. If the electron temperature is not known, the plasma parameters can only be derived from constrained O^+ and NO^+ ion distribution function models.

The extent to which auroral ion velocity distributions depart from a local Maxwellian state is important for many fields of research. For example this is an opportunity to improve the analytical solutions of the original kinetic equation, Boltzmann's equation; to improve Monte Carlo simulations by comparison to analytical approaches and vice versa. The presence of non-Maxwellian distribution functions in the auroral ionosphere is also linked to fundamental solar wind-magnetosphere coupling. It is now generally accepted that high-speed plasma convection which gives rise to non-Maxwellian distributions can be driven by momentum transfer associated with flux transfer events (Lockwood and Cowley, 1988). Moreover, the non-Maxwellian distributions produce a hydromagnetic mirror upwelling force which may control the upflows by modulating the supply of heavy ions from the ionosphere to the magnetosphere (Suvanto *et al*., 1989b). Non-Maxwellian distribution functions influence various geophysical processes such as the ion-molecular reaction rates, and also the ion composition (St-Maurice and Torr, 1978). The study of microscopic instabilities is an important topic which is not completely understood, as predictions have not yet been supported by observations (St-Maurice 1978; Kinzelin and Hubert, 1988).

We hope that this piece of work, which presents new perspectives, will be helpful to the objective measurements of non-Maxwellian plasma parameters.

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