SPEED-DEPENDENT COLLISION EFFECTS ON

RADAR BACK-SCATTERING FROM THE IONOSPHERE

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ABSTRACT

Rockets and radars are two main instruments available to experimentally investigate the collision dominated E region. But the estimates of some ionospheric parameters like density of neutrals and the electron-ion temperature ratio common to the two techniques are not in agreement. The reason for these disagreements may lie in the fact that the charge-neutral collision frequencies are assumed to be speed-independent in the estimates of ionospheric parameters by the incoherent scatter technique. However, mobility measurements and calculations indicate that the ion-neutral collision frequencies are speed-dependent. Under NASA grant NSG-7622, we have developed a computer code to accurately compute the fluctuation spectrum for linearly speed-dependent collision frequencies. We have also determined the effect of ignoring the speed-depenuence on the estimates of ionospheric parameters. It appears that disagreements between the rocket and the incoherent scatter estimates would be partially resolved if the correct speed-dependence of the i-n collision frequency is not ignored. This theoretical investigation amply justifies the need to experimentally investigate the problem. This research problem is also relevant to the study of ionospheric irregularities in the auroral E region and their effects on the radio communication with satellites.

I. Introduction

The ionosphere occupies a key position in the earth's atmosphere, which hosts probably the broadest range of physical processes and phenomena within any single physical system. The ionosphere is associated with the problems of practical interest like radio communication, satellite drag and atmospheric electricity. An accurate estimate of various parameters in this region is also important with respect to the construction of neutral atmospheric models (Salah et al., 1975; Stein and Walker, 1965; Wand, 1969). Presently, many different experimental techniques are available involving rockets, satellites, and ground-based radars to investigate the ionosphere. Because of the huge number of variables involved in ionospheric investigations, no single experimental technique can estimate all the variables. Therefore, each technique depends heavily on other techniques in estimating ionospheric parameters and in constructing ionospheric models (CIRA, 1972; Hedin et al., 1977). Also, the estimates of the parameters common to more than one technique provide checks on the accuracy of these techniques. As a matter of fact, disagreements do exist both with regards to estimates of some parameters (Brace et al., 1969; Farley, 1970, Giraud et al., 1972; Salah et al., 1975; Smith et al., 1968; Trinks et al., 1978; Wand, 1976) and with regards to the overall picture of the thermosphere (Rishbeth and Kohl, 1976). Our research efforts under NASA grant NSG-7622 have been directed towards some disagreements between the rocket and the incoherent scatter estimates of the density and composition of neutral gases and the electron-ion temperature ratio in the collision dominated E region. Our research is also relevant to the scintillations of radio signals from satellites by the irregularities in the auroral ionosphere (D'Angelo, 1968).

In the E region dominant collisions are between charged particles and neutral atoms and molecules. To the best of our knowledge, in the analysis of the incoherent scatter data the collision frequency is assumed to be speed-independent. However, mobility calculations and measurements (Dalgarno et al., 1958; McDaniel and Mason, 1973; Eisele et al., 1979, Perkins et al., 1981) indicate that i-n collision frequencies for i-n pairs relevant to the E region are in fact speed-dependent. In our past work (Behl, 1977; Theimer and Behl, 1977, 1980) we found that fluctuation spectra for linearly speed-dependent and speed-independent collision frequencies were significantly different. The computer code to compute speed-dependent plasma functions and spectra has been improved under the present grant but the above mentioned differences remained significant. We have also determined the effect of these differences on the estimates of ionospheric parameters by the incoherent scatter technique. The results of this analysis are presented in Section II. In Section III, we discuss the future plans of the research.

II. Results

i) i-n collision frequency

To see the effect of the speed-dependence of the i-n collision frequency we computed fluctuation spectra for constant and linearly speed-dependent collision frequencies. The computations for values of parameters typical to the E region are presented in Figure 1. Curve B ($y_i = \bar{y}_i v/\bar{v}_i$) has a narrower and bigger peak at $\omega = 0$ than Curve A ($y_i = \bar{y}_i$) implying that the collision effects are enhanced by the linear speed-dependence of the collision frequency. The differences between Curves A and B are larger or smaller in magnitude depending on the value of $\bar{y}_i = \bar{\nu}_{in}/k\bar{v}_i$. We have also determined by the χ^2 test the effects of these differences on the estimates of ionospheric parameters by the incoherent scatter technique. χ^2 is defined as (Alder and Roessler, 1972)

$$\chi^2 = \sum_j (e_j - o_j)^2/e_j \ ,$$

where e_j and o_j are the values of the j^{th} point of the standard spectrum and the model spectrum, respectively. A standard spectrum corresponds to speed-independent collision frequencies and a model spectrum corresponds to speed-dependent collision frequencies. We choose a set of two parameters, call them modelling parameters. One of the modelling parameters is the collision parameter $\bar{y}_i$; by varying the two modelling parameters we find the minimum-χ^2 model spectrum. By comparing the modelling parameters of the standard and the minimum-χ^2 model spectra we can estimate the effect of ignoring the speed-dependence of the collision frequency.

We have applied the above procedure to a drift-free, one ionic species plasmas using the e-i temperature ratio T_r and the ion collision parameter $\bar{y}_i$ as the modelling parameters. The inaccuracies in estimating these parameters caused by ignoring the speed-dependence are shown in the last two columns of Table I. In all the cases considered, the temperature ratio is not significantly affected, but y is over-estimated by about 40%. Since the collision frequency is proportional to the density of neutrals, this means that the density of neutrals would be over-estimated by about 40% by the incoherent scatter technique using constant collision frequencies. If the collision frequency is proportional to v^p instead, qualitatively speaking, the effects will be smaller if $p<1$ and larger if $p>1$.

In Table II, we have compared the above results with the results based on the model spectra computed by applying certain approximations (Theimer and Behl, 1980; Theimer, 1980).[†] The differences in e-i temperature ratio have been almost completely eliminated, and the differences in the estimates of $\bar{y}_1$ (i.e., the density of neutrals) have been enhanced due to the improvements in the accuracy of the computed fluctuation spectra for speed-dependent collision frequencies. Therefore, all the efforts directed towards improving the computer code seem to have been worthwhile.

We have also considered one ionic-species plasmas in the presence of electron drift relative to ions and neutrals. In this case, we computed the critical drift both for the constant and linear speed-dependent collision frequencies. The critical drift is that drift at which the value of the peak corresponding to the ion acoustic line is a maximum. It appears from the numbers presented in Table III that the critical drift will be underestimated if the speed-dependence of the collision frequency is ignored, however, the extent of underestimation would depend on the e-i temperature ratio. Incidentally, e-i temperature ratios can be quite large in the auroral E region under disturbed conditions (Ogawa et al., 1980; Schlegel et al., 1980).

ii) e-n collision frequency

The speed-dependence of e-n collisions ($\nu_{en}(v) \propto v^2$) has been incorporated in the computer code during the grant period of this report. The low frequency fluctuation spectrum of drift-free plasmas does not seem to be significantly modified even for large values (~5) of T_r; remember that the contribution of the electron line to the fluctuation spectrum increases

[†]Annual report, 1980, NASA grant NSG-7622

with increasing value of T_r. However, we did observe some modifications of the critical drift parameter when the speed-dependence of the e-n collision frequency is included.

We computed critical drift parameters for four possible combinations of the speed-dependence: both ν_{en} and ν_{in} constant; ν_{en} constant, and $\nu_{in} \propto v$; $\nu_{en} \propto v^2$, and ν_{in} constant; and both ν_{en} and ν_{in} speed-dependent. The results are tabulated in Table IV. The e-i temperature ratio in all cases is equal to 1.0. The critical drift parameter is decreased when e-n collisions are not neglected. A comparison of columns three and five in Table IV indicates that this decrease is enhanced when the quadratic speed-dependence of the e-n collision frequency is included. These effects are smaller or larger depending on the values of $\bar{y}_e$ and $\bar{y}_i$. However, the effect of including the speed-dependence of the i-n collision frequency (compare columns five and six of Table IV) is to slightly increase the critical drift parameter. These effects need to be investigated more fully for higher e-i temperature ratios.

The results of this section were presented in the Fall 1981 meeting of American Geophysical Union at San Francisco.

III. Future Research Plans

Our results based on the exact computations of fluctuation spectra for the speed-dependent collision frequencies clearly establish that ignoring the speed-dependence of ion-neutral collisions would significantly modify the incoherent scatter estimates of the density of neutrals. However, these results are based on the theoretical analysis, and therefore, need to be checked experimentally. To perform the radar back-scattering experiment, we shall need to go to some national lab like the Arecibo

Observatory in Puerto Rico. It takes about six months for the approval for the radar time (Dr. M. Sulzer, the Arecibo Observatory, private communications), and 3-4 months to analyze the data. This experimental investigation will help us obtain more accurate estimates of the density of neutrals and, in all likelihood, will lead to better agreements between the rocket and the incoherent scatter estimates.

Many theoretical aspects of the problem could also be investigated, either in lieu of or in addition to, the above mentioned experimental investigation. For example, the phenomenon of ion-acoustic instabilities, i.e., estimates of critical drift parameters and the corresponding wavelengths, needs to be investigated further through literature survey and the theoretical analysis of the kind discussed in Section II. Currents large enough to excite ion-acoustic instabilities do occur in the auroral E region, and the related problems like scintillations of radio signals are of practical importance in the radio communication with satellites (D'Angelo, 1968).

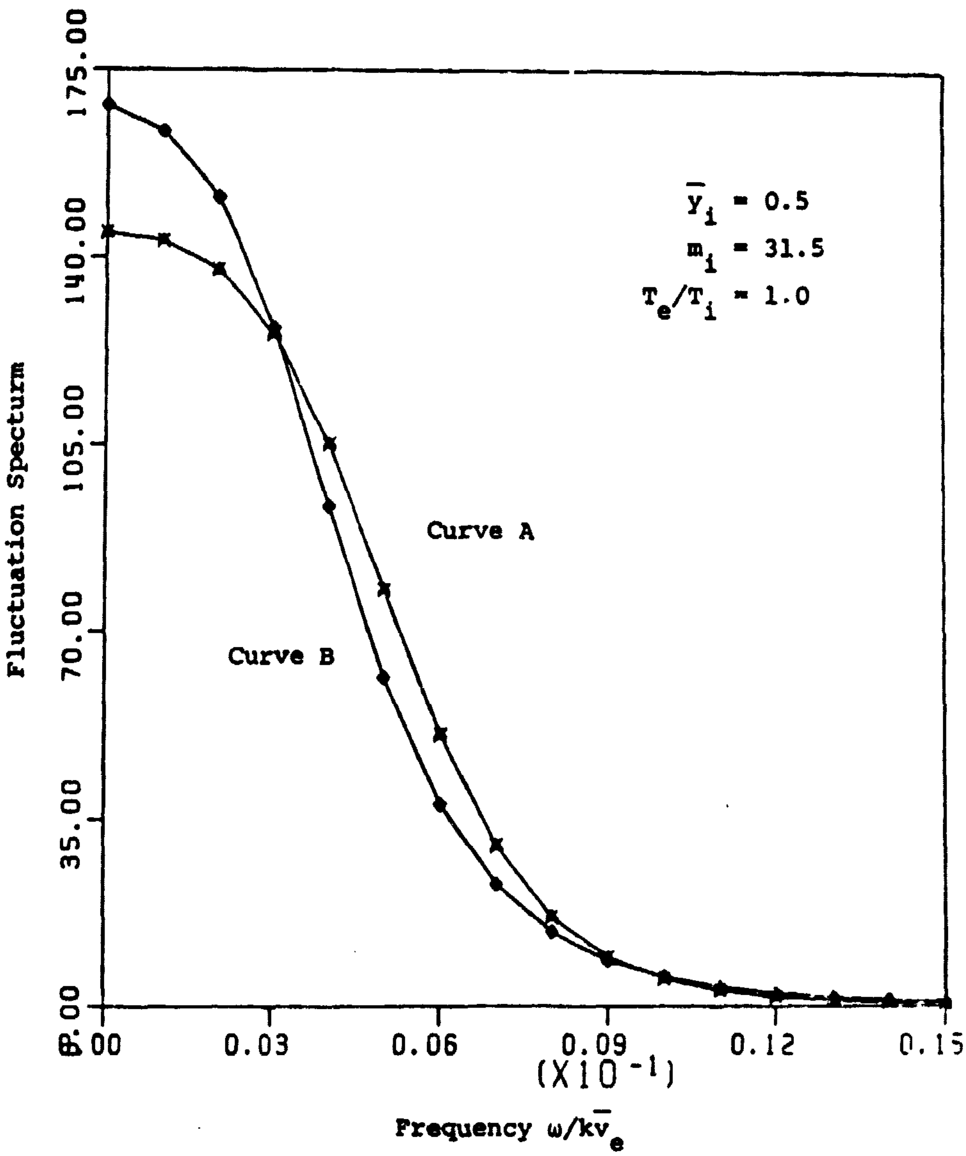

Figure 1. The fluctuation spectrum as a function of normalized frequency $\omega/k\bar{v}_e$. Curve A corresponds to a speed-independent collision frequency and Curve B corresponds to linearly speed-dependent collision frequency.

Table I. One ionic-species plasmas without drift. T_r is the e-i temperature ratio; $\bar{y}_i = \bar{\nu}_{in}/k\bar{v}_i$, where k is the wave number and $\bar{v}_i$ is the ion thermal speed.

Standard Spectrum		Minimum-χ^2 Model Spectrum		% Difference	
T_r	$\bar{y}_i$	T_r	$\bar{y}_i$	T_r	$\bar{y}_i$
1.00	0.20	0.98	0.12	2	40
	0.30	0.98	0.17	2	43
	0.40	0.98	0.24	2	40
	0.50	0.97	0.30	3	40
1.50	0.50	1.47	0.30	2	40
2.00	0.50	1.96	0.29	2	42

Table II. Comparison of results of the minimum-χ^2 analysis for model spectra computed by using a semi-linear approximation and computed numerically using no approximations.

Standard Spectrum		% Difference Between Standard and Minimum-χ^2 Model Spectra			
		Semi-Linear Approx.		Exact	
T_r	$\bar{y}_1$	T_r	$\bar{y}_1$	T_r	$\bar{y}_1$
1.00	0.20	26	25	-2	40
	0.30	34	33	-2	43
1.50	0.20	14	27	-2	45
	0.30	19	37	-2	43
2.00	0.20	8	45	-2	45
	0.30	12	43	-2	43

Table III. Critical drift parameters of one ionic-species plasmas for speed-independent and speed-dependent i-n collision frequencies; e-n collision frequency is set equal to zero.

T_r	$\bar{\nu}_i$	Critical Drift Parameter		% Difference
		$\nu_i = \bar{\nu}_i$	$\nu_i = \bar{\nu}_i \, v/\bar{v}_i$	
1.0	0.2	1.02	1.02	0
3.0	0.1	0.40	0.44	10
	0.2	0.46	0.51	11
	0.3	0.51	0.56	10
5.0	0.1	0.23	0.28	22
10.0	0.1	0.08	0.12	50

Table IV. Critical drift parameters of one ionic-species plasmas for speed-independent and speed-dependent i-n and e-n collision frequencies; T_r is equal to 1.0

$\bar{y}_e$	$\bar{y}_i$	Critical Drift Parameters			
		$y_e = \bar{y}_e$, $y_i = \bar{y}_i$	$y_e = \bar{y}_e$, $y_i = \bar{y}_i\ v/\bar{v}_i$	$y_e = \bar{y}_e\ v^2/\bar{v}_e^2$, $y_i = \bar{y}_i$	$y_e = \bar{y}_e\ v^2/\bar{v}_e^2$, $y_i = \bar{y}_i\ v/\bar{v}_i$
0.00	0.30	1.04	1.07	1.04	1.07
0.11	0.30	0.98	1.01	0.95	0.97
0.00	0.50	1.09	1.12	1.09	1.12
0.18	0.50	1.00	1.03	0.95	0.98
0.00	0.80	1.14	1.17	1.14	1.17
0.29	0.80	1.01	1.06	0.93	0.96

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