Problems in Explaining the Behaviour of the F1 Layer

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Experimental and theoretical curves of the diurnal variation of electron plasma frequency in the height range 120 to 200 km are compared in the latitude range 32° to 78°S. It is shown that at very high latitudes (Scott Base, 78°S, L = 34) the F1 layer is almost completely under solar control in summer and that ionization below 200 km disappears almost completely during the winter polar night.

At moderately high latitudes (Halley Bay 75°S, Sanae 70°S, L = 4) the results indicate that the F1 layer is caused by a combination of a flux of precipitated electrons and solar extreme ultraviolet radiation (XUV) in both winter and summer. The precipitated electrons are the dominant cause in winter and the solar XUV radiation the main cause in summer. Comparison between experimental and theoretical results for Argentine Island (65°S, L = 2,4), Godley Head (44°S, L = 2,4) and Mundarin (32°S, L = 1,76) indicate that the agreement becomes very much worse towards lower geographical latitudes if ionization only by solar XUV radiation is taken into account. The discrepancy is most pronounced in winter and it is shown that it cannot be explained in terms of variations in normal aeronomic parameters. Since there is no evidence of a permanent corpuscular energy influx at middle latitudes, no explanation is offered at this stage for this discrepancy.

Eksperimentele en teoretiese krommes van die daaglikse wisseling van die elektronplasmafrekwensie in die hoogtebereik van 120 tot 200 km word vergelyk vir die breedtes 32°S tot 78°S. Daar word aangetoon dat die F1-laag by baie hoë breedtes (Scott Base, 78°S, L = 34) gedurende die somer so te sê volmaak deur die son beheer word en dat die ionisasie onder 200 km gedurende die winter poolnag so te sê geheel en al verdwyn.

By redelike hoë breedtes (Halley Bay, 75°S, Sanae 70°S, L = 4) dui die resultate daarop dat die F1-laag deur 'n kombinasie van 'n neerslag van instromende elektrone en verre-ultravioletsonsbestraling gedurende sowel die winter as die somer veroorsaak word. Die instromende elektrone en verre-ultravioletsonsbestraling is die heersende oorsaak gedurende onderskeidelik die winter en die somer. 'n Vergelyking tussen eksperimentele en teoretiese resultate vir Argentine-eiland (65°S, L = 2,4), Godley Head (44°S, L = 2,4) en Mundarin (32°S, L = 1,76) dui daarop dat die ooreenstemming na laer geografiese breedtes toe baie verswak indien ionisasie slegs deur verre-ultravioletsonsbestraling in ag geneem word. Die verskil is die merkbaarste gedurende die winter en daar word aangetoon dat dit nie in terme van wisselinge in gewone aëronomiese parameters verklaar kan word nie. Aangesien daar geen aanduiding van energie-instroming van permanent gelaaide deeltjies by middelbreedtegrade is nie, word daar in hierdie stadium geen verklaring vir hierdie verskil aan die hand gedoen nie.

Introduction

In a previous paper (*Torr et al.*, 1972, which will henceforth be referred to as paper 1) we compared observed and theoretical values of the diurnal variation of plasma frequency at Sanae (70°S, 2°W, L = 4) in the height range 120 to 200 km for selected days during the period June to December 1966. The theoretical model of the ionosphere that we used is essentially the same as that published by *Keneshea, Narcisi & Swider* (1970) for the E layer. Fairly good agreement was obtained between experiment and theory for early November, but very poor agreement (a difference of a factor of $\sim$ 1,5) for winter. In paper 1 it was shown that the discrepancy in winter disappears if one takes into account the precipitation of low energy electron fluxes with approximately the same characteristics as those observed by *Schield & Frank* (1970) and *Heikkila & Winningham* (1971).

In this paper we extend the analysis over a larger range of latitudes.

Presentation of Results

Fig. 1 shows the results for Scott Base for 4 November, 1962. Precipitated particles have been omitted from this calculation. The agreement between experiment and theory is excellent, indicating that the F1 layer over Scott Base in summer is solar controlled. This is consistent with the zones of particle precipitation reviewed by *Paulikas* (1971) which show a sudden decrease in precipitation in the vicinity of 80° invariant latitude (equivalent to L = 34).

Fig. 2 shows the results for Scott Base for 20 June, 1962. The agreement is also good because practically no ionization is observed below 200 km and nearly all values of plasma frequency lie below 1 MHz. The observed ionization near noon is probably caused by solar XUV radiation because of its connection with the theoretical values. However, Fig. 32 of *Paulikas*' (1971) paper, which is a synthesis of the work of *Burch* (1970) and *Craven* (1970), shows that Scott Base probably lies near the inner boundary of the

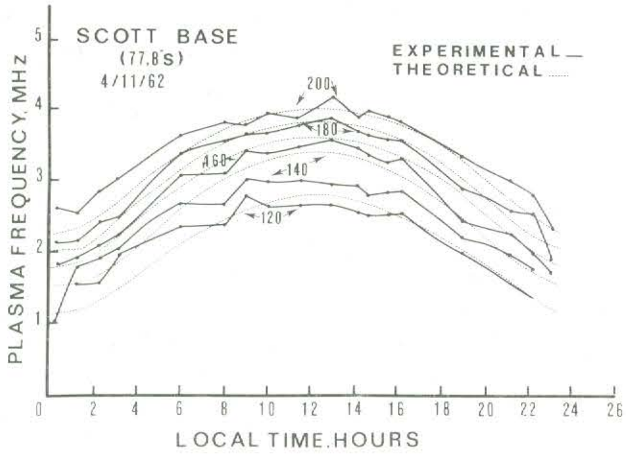

Fig. 1. The diurnal variation of theoretical values of plasma frequency superimposed on the experimental observations of 4 November, 1962 for Scott Base with solar XUV as the only ionizing radiation for the height range 120 to 200 km. $\Sigma\ Kp = 26$.

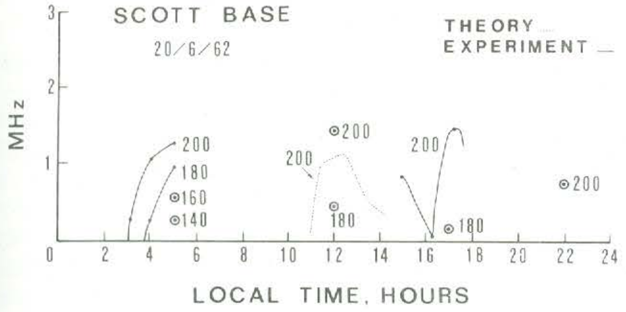

Fig. 2. Same as Fig. 1 for 20 June, 1962. $\Sigma\ Kp = 8$.

500 eV electron zone at night when the average fluxes are higher than during the day; but during the day, the station probably lies in the heart of the 0,5 keV electron precipitation zone when the fluxes reach a minimum. The ionograms for Scott Base show spread F in the F2 layer as a regular feature both in summer and winter which is typical of that expected for particle precipitation effects. The fact that the F1 layer height range is hardly affected by these particles places a clear cut maximum on their energy range, and this is quite consistent with the characteristics reviewed by *Paulikas* (1971). It therefore seems highly probable that the ionization observed between 03 to 06, 15 to 18 and at 22 hours is caused by the precipitation of low energy electrons or protons.

Fig. 3 shows the results for Halley Bay for 4 November, 1962. Halley Bay lies on approximately the same L shell as Sanae (L = 4,2), but 5° higher in latitude (75,5°S). The results are very similar to the summer results for Sanae given in paper 1. On the basis of the solar XUV model the nighttime theoretical values of plasma frequency lie below the observed. As in the case of Sanae, the discrepancy between experiment and theory can be removed by including in the calculations a flux of precipitated electrons with characteristics similar to those reported for Sanae in paper 1.

Fig. 4 shows the summer results for Argentine Island (65°S, L = 2,4) which lies 5° further north than Sanae. Fig. 5 gives the same results for a station on the same L shell (Godley Head, 44°S, L = 2,4), but another 20° further north. These results show a deterioration with decreasing latitude in the ability of the model to account for the observed values of plasma frequency at heights above 160 km.

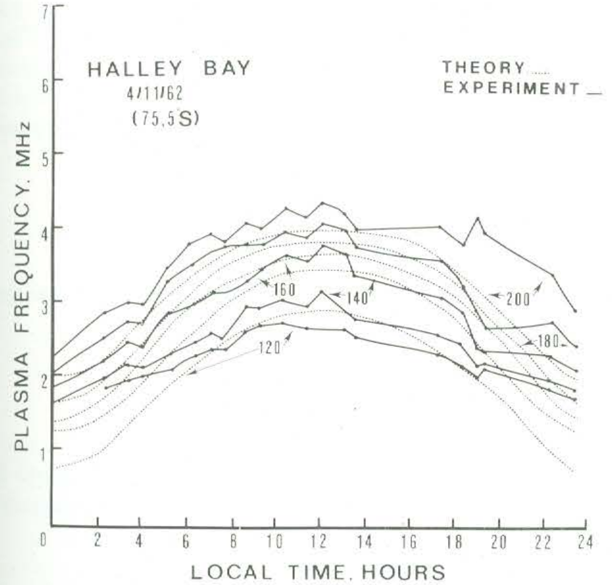

Fig. 3. Same as Fig. 1 for Halley Bay.

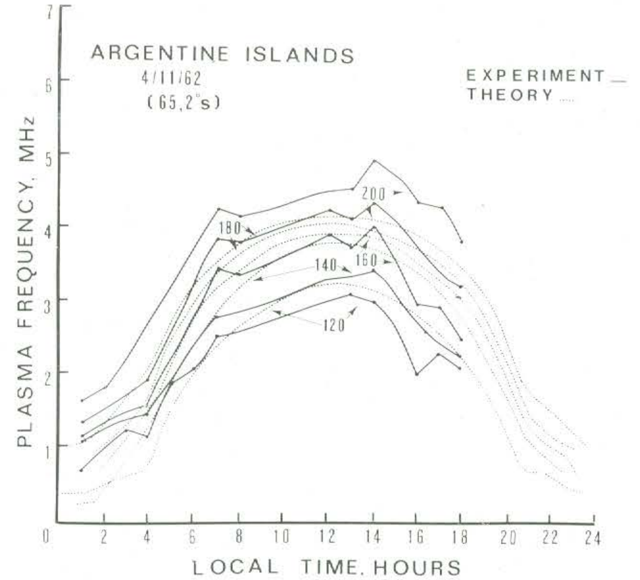

Fig. 4. Same as Fig. 1 for Argentine Islands.

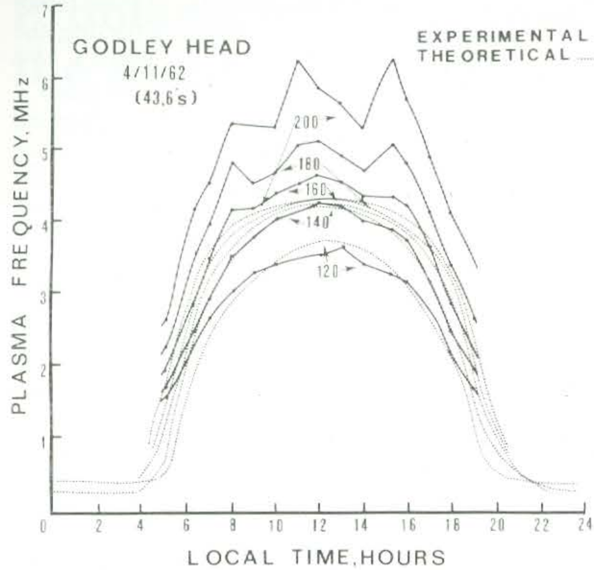

Fig. 5. Same as Fig. 1 for Godley Head.

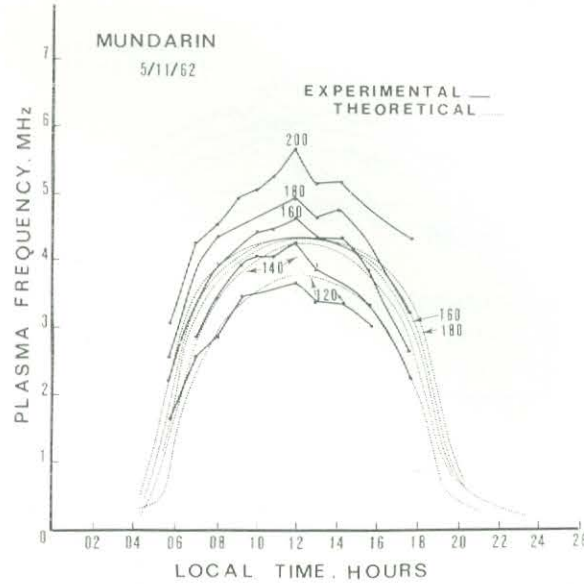

Fig. 7. Same as Fig. 1 for Mundarin for 5 November, 1962. $\Sigma\, Kp = 11$.

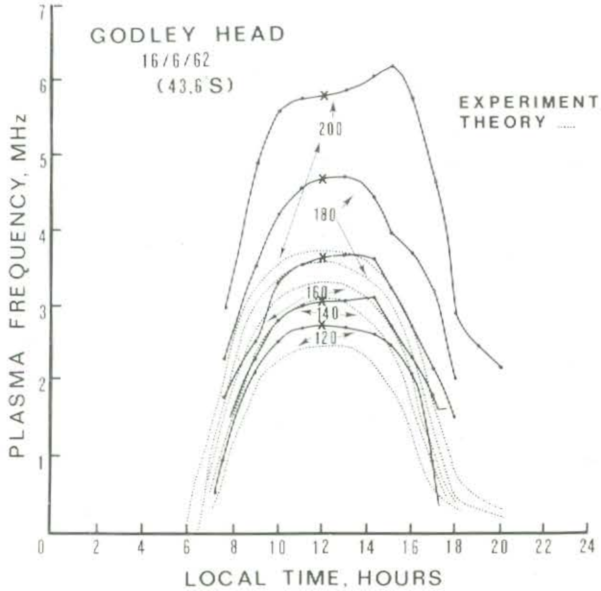

Fig. 6. Same as Fig. 1 for Godley Head for 16 June, 1962. $\Sigma\, Kp = 11$.

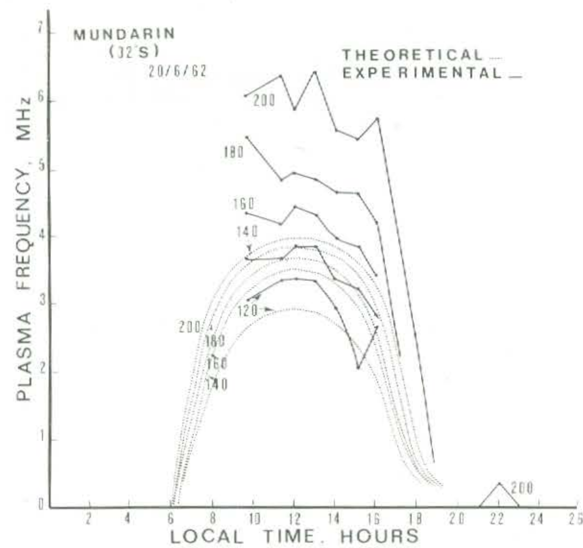

Fig. 8. Same as Fig. 1 for Mundarin for 20 June, 1962.

Fig. 6 shows the results for Godley Head for 16 June, 1962. The crosses are median values calculated from data for five days near 16 June, 1962. This illustrates that the large discrepancy between experiment and theory in winter is not an isolated event. Figs. 7 and 8 show that the phenomenon persists at latitudes as low as 32°S. This is a surprising result in view of the agreement found for the Scott Base results. The latter seemed to indicate that the model would satisfactorily explain the behaviour of the ionosphere if solar XUV radiation were the only source of ionization, and it is generally believed that the ionosphere becomes increasingly solar controlled towards lower latitudes.

Investigation of Possible Causes

The model proposed by *Keneshea, Narcisi & Swider* (1970) is of the form:

$$\frac{dN}{dt} = Q - L$$

where N is the electron density, t is time and Q and L are the ion pair production and loss rates respectively.

Neglect of Transport Effects

The first question that arises concerns the validity of the model. Can transport effects be neglected at heights below 200 km? To test whether this is so we have run a comprehensive version of the ionospheric continuity equation (*Torr & Torr*, 1970) for the Mundarin summer case and we found that the effect of diffusion and winds on the plasma frequency is less than 3% at noon, but that diffusion can increase the theoretical nighttime values from 0,2 MHz to 0,8 MHz at 30°S at 200 km. The effect of diffusion decreases rapidly with decreasing altitude and is totally insignificant below 160 km. The effect of winds at night is to decrease the ion density between 150 and 200 km (*Stubbe*, 1971). Thus it is clear that the discrepancy cannot be explained in terms of transport effects.

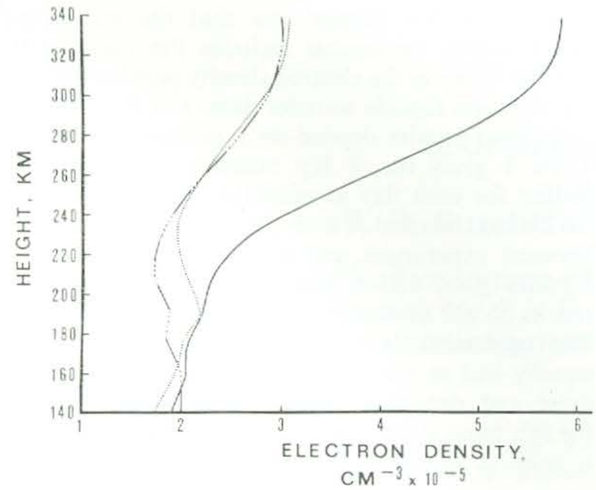

Fig. 9. Theoretical N(h) profiles showing the effect of composition changes in the F1 and F2 layers. The control curve (full line) was calculated using Jacchia's (1965) model atmosphere. The dotted curve shows the effect of doubling the molecular number densities O_2 and N_2 and the dashed curve the effect of halving the atomic constituent number densities. The calculations were done for 30°S, noon sunspot minimum summer conditions.

Composition Changes

Fig. 9 gives the effect of various composition changes on the theoretical N(h) profile. It shows that while an increase by a factor of 2 in the densities of N_2 and O_2 hardly affects the height range below 200 km, it dramatically affects the F2 layer. This rules out the possibility of composition change being able to explain the discrepancy between observation and theory for Mundarin and Godley Head in winter.

Reaction and Production Rates

At 200 km, where the discrepancy is greatest, the model lies in the transition region between the 'linear' type loss formula $L = \beta N$ and the 'square' type loss formula $L = \alpha N^2$ discussed by *Hirsch* (1959). This is a convenient way of looking at a rather more complex problem: β and α are the linear and quadratic recombination coefficients respectively. In our model the plasma frequency at 200 km changes approximately as the cube root of Q ($Q^{0,30}$) and/or reaction rates. At this height the experimental and theoretical results for Mundarin and Godley Head differ by a factor of ~1,5. This implies a discrepancy of a factor of ~4 in the calculation of the production rate, or in the reaction rates. It hardly seems possible to account for such a large variation in these parameters. Furthermore, any change that occurs must be a result of both a latitudinal and height dependence in order not to spoil the excellent agreement between experiment and theory at high latitudes and at 120 – 140 km altitude at all latitudes discussed.

Conclusion

The results presented in this paper show that, especially at middle latitudes, the behaviour of the F1 layer cannot be explained only in terms of a model involving production of ionization by solar XUV radiation and the chemical scheme of *Keneshea, Narcisi & Swider* (1970) (which yields excellent agreement between experiment and theory at E layer heights over a large range of latitude). It is also shown that there is no obvious way of explaining this phenomenon in terms of variations in the usual aeronomic parameters.

Although particle precipitation would provide an obvious solution to this problem, there is no direct evidence to support the idea of particle precipitation at middle latitudes. Neither do the mid-latitude ionograms show the erratic type of behaviour characteristic of high latitudes where particle precipitation is an important phenomenon.

Table 1

Station	Latitude	L Shell	Summer Date	Summer Kp	Summer A	Winter Date	Winter Kp	Winter A
Scott Base	78°S	34,00	4.11.62	26	G	20.6.62	8	G
Halley Bay	75°S	4,21	4.11.62	26	G			
Argentine Islands	65°S	2,36	4.11.62	26	G			
Godley Head	44°S	2,40	4.11.62	26	B	16.6.62	11	B
Mundarin	32°S	1,76	5.11.62	11	B	20.6.62	8	B

A referee has pointed out that the mid-latitude region which we discuss includes the plasma-pause and the valley in the electron density profiles shown by the Alouette topside sounder data, and that the exact latitudinal profiles depend on a geomagnetic activity. Table 1 gives the Σ Kp magnetic index for each station for each day investigated. Also shown under the column labelled A is an indicator of the agreement between experiment and theory above 160 km. G signifies good and B bad agreement. These limited results do not show any significant magnetic influence. The agreement between experiment and theory is equally bad at the two mid-latitude stations on both quiet and disturbed days (4 November, 1962 was the 9th most disturbed day of that month). The fit is good at high latitudes on all days.

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