The Effects of a Partial Solar Eclipse on the Ionosphere at Sanae

Marsha R. Torr
and
D. G. Torr
National Institute for Telecommunications Research of the Council for Scientific and Industrial Research.

Abstract

A partial solar eclipse at Sanae is examined and a comprehensive version of the steady-state ionospheric continuity equation is solved for theoretical comparison. The results confirm previous conclusions, drawn from an analysis of eclipses at other stations, that it is impossible to reproduce the ionospheric eclipse effects satisfactorily if the only source of ionization used is solar EUV radiation. Part of the ionization appears to be unaffected by the eclipse and if a corpuscular source of ionization is included there is much better agreement between observation and theory than when it is not included.

Introduction

In a previous publication (*Torr and Torr*, 1971) which will be referred to subsequently as Paper I, two partial solar eclipses were examined, each from two different stations. Observations made at Cape Town and Johannesburg of the eclipse of 25th December 1954, and at Grahamstown and Syowa Base of the eclipse of the 11th August 1961, were examined and compared with theory. A comprehensive version of the steady-state ionospheric continuity equation was solved for purposes of theoretical comparison. In Paper I it was shown that it was impossible to reproduce the ionospheric eclipse effects satisfactorily if the only source of ionization used was solar EUV radiation. The decrease in peak electron density during the eclipse calculated when only EUV was considered, was so much larger than was observed that another source, unaffected by the eclipse, must have been acting throughout the eclipse. It was found that when a corpuscular source of ionization was included the theoretical results were in better agreement with the observed results than when it was not included.

In this paper, a similar analysis is done of a partial eclipse which occurred at the Antarctic station Sanae (70°S, 2°W) on 14th January 1964, in order to establish whether the same conclusions are valid for this station. Details of the various phases of the eclipse are given in Table 1.

Observations and Theoretical Calculations at Sanae

The solution of the steady-state case of the ionospheric continuity equation has been described in a previous paper (*Torr and Torr*, 1969) and the application of this solution to the analysis of a solar eclipse was described in Paper I. The main condition that must be met is that $dN/dt \lesssim 10\%$ of the production rate over the entire height range and this is satisfied in the case of the present analysis. The procedure followed here is essentially the same as that described in Paper I. *CIRA* (1965) model atmosphere 2 is used.

The observed N(h) profiles for a time corresponding to the eclipse maximum and start are shown in Figures 1 and 2 respectively for both the eclipse day and the day following the eclipse which will be used as the control. Both these days were magnetically quiet. Values of foF2 can fluctuate by as much as 10 per cent from hour to hour on normal days at most stations. At Sanae, which is well known for its disturbed nature, fluctuations of up to 20 per cent can be considered normal. However, any deviation of the eclipse day from the control day at the time of eclipse maximum lies within 5 per cent in the height range of the F2 layer (>220km). Between 100 to 220 km the eclipse day shows a decrease of up to 30 per cent compared with the control day.

If one takes into account the fact that at the start of the eclipse, the densities on the eclipse day were up to ~15 per cent higher than on the control day, it can be concluded that the effect of the eclipse is a decrease of not more than ~45 per cent in the E and F1 layers and of not more than ~15 per cent in the F2 layer. However, it should be borne in mind that hour to hour fluctuations in foF2 alone could account for the variations in this parameter.

Curve 1 in Figure 1 shows the results of solving the steady-state equation with no additional source of ionization, using current laboratory measurements of the reaction rates. It is necessary to multiply the production rate by a factor of 4 to obtain a profile of the

Table 1

Altitude, km	100			200			300		
	h	m	s	h	m	s	h	m	s
Eclipse start (UT = LT)	20	00	07	19	59	41	19	59	18
maximum	20	53	20	20	53	36	20	53	52
end	21	45	10	21	46	05	21	46	56
Maximum obscuration		42%			45%			48%	

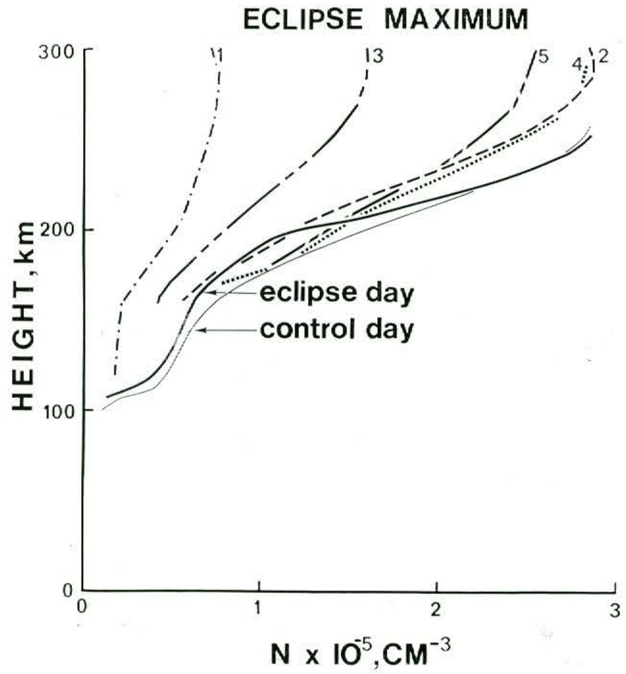

Fig. 1. Observed and calculated profiles at the time corresponding to eclipse maximum. The labelled full lines are the observed profiles on the eclipse day and the control day. Curve 1 is the calculated profile if only an EUV source is used. In curve 2, the EUV production rate of (1) is multiplied by a factor of 4. Curve 3 is the profile obtained when the EUV source of (2) is reduced by 48 per cent to simulate the eclipse. Curve 4 is the profile obtained using the EUV source of (1) and a corpuscular source. In curve 5 the EUV source has been reduced by 48 per cent to simulate an eclipse while the corpuscular source remains unchanged.

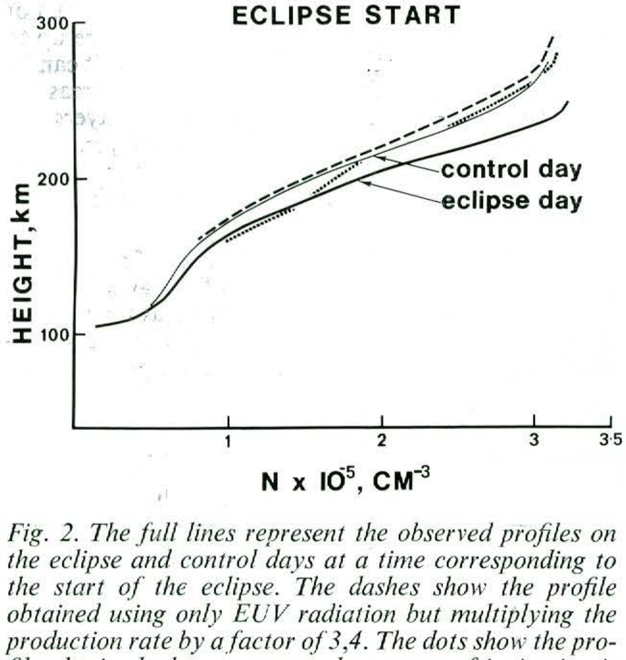

Fig. 2. The full lines represent the observed profiles on the eclipse and control days at a time corresponding to the start of the eclipse. The dashes show the profile obtained using only EUV radiation but multiplying the production rate by a factor of 3,4. The dots show the profile obtained when a corpuscular source of ionization is included in the calculation.

same magnitude as that observed (curve 2). In the case of the mid-latitude stations examined in Paper I, it was found that the factor required to fit the lower ionosphere (below $\sim$ 200 km) was different to that required to fit the F2 region. In this case however, the use of a single factor resulted in fair agreement with observation over the whole altitude range. If the production is then reduced by 48 per cent – the percentage of maximum obscuration of the solar disc – then the F2 peak drops to that shown in curve 3 i.e. a drop of a factor of 1,8 in Nm F2, although no such drop is observed.

It therefore appears that a solar eclipse at Sanae follows the pattern of the eclipses examined in Paper I and cannot be satisfactorily reproduced on the basis of the theory described above, if the only source of ionization is EUV radiation.

As in Paper I the indications are that part of the ionization is due to a steady background source, unaffected by an optical eclipse. The calculations were therefore repeated using a second ionization source due to low energy electrons (50–750eV). Curve 4 in Figure 1 shows the results of this using an energy spectrum of the form exp $(-e/5)$ where e is the energy at the top of the atmosphere and a flux of $2{,}1 \times 10^9$ cm $^{-2}$ sec $^{-1}$ at 50eV.

In curve 5, the EUV production has been reduced by 48 per cent while the corpuscular source remains unchanged. The agreement with observation is not as good here as it was in the case of the mid-latitude stations examined in Paper I, but it is certainly better than that obtained when no corpuscular source is included. Indications are that a somewhat different particle energy spectrum is required at Sanae to obtain the best agreement with observation.

The height of the calculated peak electron density (in the case of curves 1 to 5) is about 20km above the observed height. This may be because the actual vertical drift component is larger than the calculated (which is from 0 to -5m.sec $^{-1}$ at these times). The discrepancy in height may also be due to a difference between the actual atmospheric temperature and that of the model atmosphere used.

In the same way an attempt was made to fit the start of the eclipse at 20,00 L.T. and the results of this are shown in Figure 2. As before, when only EUV ionization was used, the resultant electron density was too small. However, reasonable agreement was obtained when the production rate was multiplied by a factor of 3,4.

The inclusion of a corpuscular source of ionization with a flux of 2×10^9 cm $^{-2}$ sec $^{-1}$ also gave good agreement. The slight difference in the factor and flux required compared with eclipse maximum probably falls within the normal F-region fluctuations.

Shortly after the eclipse maximum on 14th January 1964, a sporadic E-layer prevented calculation of N(h) profiles for that day until just after the final phase of the eclipse. However, the control day profile will be used for comparison with theory. The results of this are shown in Figure 3. Fairly good agreement with observation is obtained if a flux of 4.5×10^9 cm $^{-2}$ sec $^{-1}$ with a slightly softer spectrum (50 to 500eV) is used or if the EUV production rate is multiplied by a factor of 7. In this case therefore, there are indications that the corpuscular spectrum softens towards night and that the total energy influx due to the second source increases.

Comparison of the Two Sources

Height profiles of the two production rates at 21.00 hours together with the percentage contribution that each makes to the total are shown in Figure 4. This diagram makes it very clear how inadequate the EUV production is in shape and magnitude (on the basis of the theory described above) to account for the observed ionosphere at Sanae at this time of day.

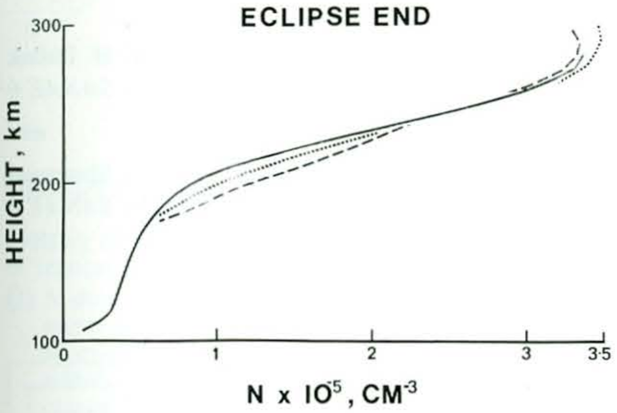

Fig. 3. The full line represents the observed control day profile at a time corresponding to the end of the eclipse. The dashes show the profile obtained using only EUV radiation but multiplying the production rate by a factor of 7. The dots show the profile obtained when a corpuscular source of ionization is included in the calculation.

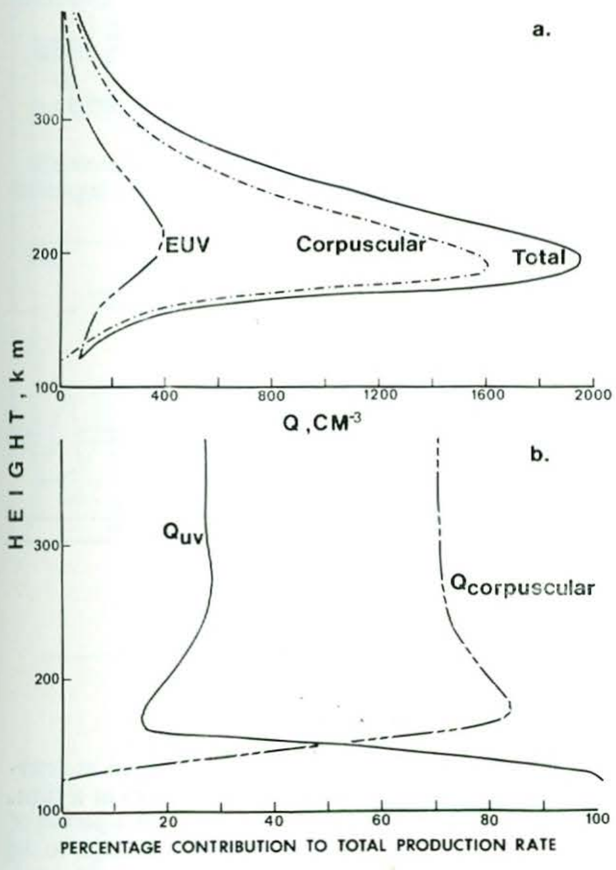

Fig. 4.

(a) Height profiles of the two production rates.

(b) The percentage contribution of the EUV and corpuscular production rates to the total.

A similar comparison for Johannesburg in Paper I showed that the percentage production rate due to EUV continued to decrease steadily above 160 km, in contrast to the calculations for Sanae in which the EUV percentage production rate peaks again at 280 km, and the corpuscular percentage production rate peaks at 180 km. This is due to the fact that the EUV maximum production occurs at a higher altitude at this time of the day at Sanae.

Conclusions

The results presented here support the main conclusion drawn in Paper I, namely that using current solar spectral intensities, absorption and ionization cross-sections, and laboratory-measured reaction rates, it is impossible to explain satisfactorily the behaviour of the F2 layer on the basis of the theory described in Paper I, if EUV is the only source of ionization. At the times for which the calculations were done, it is necessary to multiply the EUV production rates by a factor of up to 7 to obtain the observed electron densities. It is unlikely that the parameters used could be inaccurate by as much as this. Using such a factor, the decrease in NmF2 obtained at eclipse maximum is far greater than the observed decrease.

Although the inclusion of a second source of ionization in the form of low energy electrons with an energy flux $\sim 10^{11}$eV cm^{-2} sec^{-1} gives N(h) profiles in fairly good agreement with the observed, further observations are required to confirm the nature of this second source. However, regardless of this, an analysis such as that described here provides some details concerning the magnitude and variation with time and space of the second source.

It appears that in order to obtain the best agreement with the observed profiles the energy spectrum must vary with location and time. Probably, however, these variations are small. In other words, the energy fluxes required at the high latitude stations Sanae and Syowa Base are roughly the same as those required at the mid-latitude stations, Grahamstown, Cape Town and Johannesburg. There are indications of a diurnal variation in the second source and this will be examined more fully in a future paper.

Acknowledgements

We are grateful to the Department of Physics, Rhodes University, Grahamstown for providing the Sanae ionograms; to the Department of Transport for facilities in Antarctica, and to Dr W. Becker of the Max Planck Institute for Aeronomy, Lindau/Hartz, for his computer programme for the reduction of ionograms to N(h) profiles. The Republic Observatory, Johannesburg, provided the details concerning the times of the different phases of the eclipse given in Table 1. Our thanks go to Mr R. W. Vice for reading the manuscript.

References

CIRA, Cospar International Reference Atmosphere, North Holland Publishing Co. Amsterdam, 1965.

Torr, M. R. and Torr, D. G. The inclusion of a particle source of ionization in the ionospheric continuity equation. *J. atmos. terr. Phys.* 31, 611–614, 1969.

Torr, M. R. and Torr, D. G. The ionosphere during a solar eclipse. *J. atmos. terr. Phys.*, 33, 527–537, 1971.