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Electron Content

RESPONSE OF THE TOTAL ELECTRON CONTENT OF THE IONOSPHERE OVER NORTH AMERICA TO THE TOTAL SOLAR ECLIPSE OF 26 FEBRUARY 1979*

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Ionospheric total electron content (TEC) observations were carried out from eight stations during 26 February 1979 total solar eclipse over North America. The TECs were determined from the Faraday rotation of the plane of polarization of the VHF signal from geostationary satellites. Local times of totality of the eclipse in the ionosphere observed from the various stations ranged from 0734hr to 1400hr. Depletion of the ionospheric total electron content from the non-eclipse average behaviour varied up to a maximum of 40 per cent for the ionosphere experiencing 100 per cent eclipse. Maximum TEC depletion occurred on average 33 minutes after maximum contact. Most of the stations showed a rapid rate of depletion of TEC about 30 minutes after first contact, the rate of depletion reaching a minimum value at or before maximum obscuration. Before fourth contact was reached, the rate of increase of TEC generally had overshot the non-eclipse day average, gradually returning to that average after the fourth contact. Using ionosonde data, it was found that the peak density of the F-region and the TEC varied by approximately the same amount at those stations for which the E-region had formed before first contact of the eclipse. Slab thicknesses were not significantly changed during the eclipse.

Keywords: Total Electron Content; Faraday Rotation; Plane of Polarization; VHF Signal; Geostationary Satellite; Ionograms

INTRODUCTION

EARLY research into ionospheric eclipse effects revolved around ground based techniques such as vertical incidence ionosondes and fixed frequency transmissions (Beynon & Brown, 1956). These techniques have now been supplemented by rocket and satellite studies as well as incoherent backscatter measurements (Rishbeth, 1968;

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and *J. atm. terr. Phys.*, **34**(4), 1972). The advent of geostationary satellites in conjunction with ionosonde measurements have enabled a more detailed study of the spatial and temporal variation of the eclipse effects to be performed (Klobuchar & Malik, 1970). Recently, interest has centered on the production of artificial holes in the ionosphere produced by rockets (Mendillo *et al.*, 1975, 1979) and the space shuttle (Mendillo *et al.*, 1978).

The total solar eclipse of 26 February 1979 provided an opportunity to study the response of the F-region of the ionosphere over North America during the production of a naturally occurring hole. Previous eclipses have produced both increases in the peak density of the F-regions (Evans, 1965) and decreases (Marriott *et al.*, 1972).

Observations

Ionospheric total electron content (TEC) observations were carried out from eight stations during 26 February 1979 total solar eclipse over North America. The TEC was determined from the Faraday rotation of the plane of polarization of the VHF signal from a suitably located geostationary satellite, using the method of Titheridge (1972). From one of the stations, Hamilton, observations were made using four satellites. Fig. 1 shows the location of the stations together with the 420km sub-

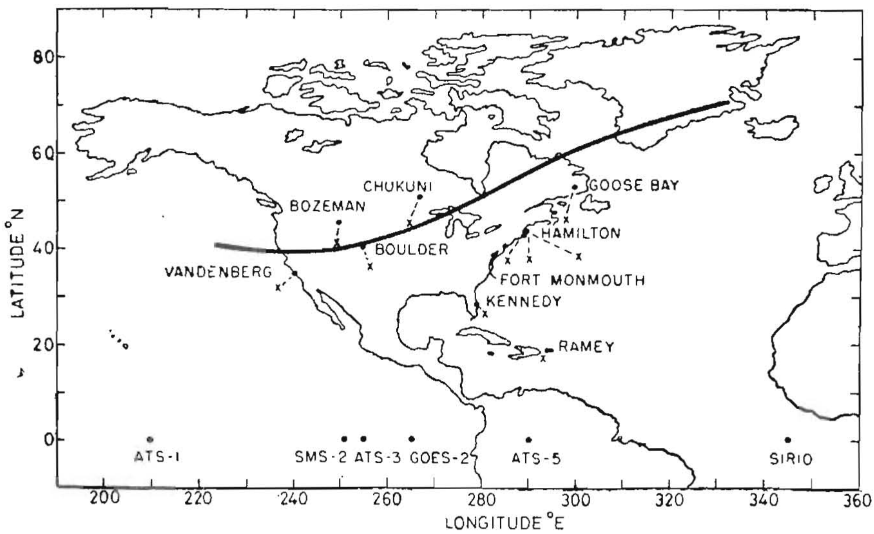


FIG. 1. Map showing the centre line of path of totality at 420km for 26 February 1979 solar eclipse over North America. The TEC stations are shown together with the 420km sub-ionospheric points (crosses) along the ray paths to the geostationary satellites. The nominal sub-satellite positions of the various geostationary satellites are also shown.

ionospheric point along the ray path to the satellite. The sub-satellite locations of the satellites are also shown. The continuous line indicates the centerline path of totality of the eclipse at 420km. Table I lists the TEC stations, satellite beacons, and the 420km sub-ionospheric points and their invariant latitudes. As well, ionosonde stations and their locations are indicated.

TABLE I

Total electron content observation sites and ionosonde locations

TEC Station	Satellite	420km sub-ionospheric point Latitude °N	Longitude °W	Λ °N
Goose Bay	ATS–5	46.2	62.4	60
Chukuni	ATS–3	45.6	95.5	58
Bozeman	SMS–2	41.3	110.5	51
Hamilton	ATS–3	38.5	75.9	53
	SMS–2	38.5	76.7	53
	SIRIO	38.1	59.8	51
	ATS–5	37.9	70.7	53
Boulder	GOES–2	36.5	104.0	47
Vandenberg	ATS–1	31.8	123.8	39
Kennedy	ATS–5	26.3	79.6	41
Ramey	ATS–5	17.1	67.4	36

Ionosonde Station	Latitude °N	Longitude °W	Λ °N
Fort Monmouth	40.2	74.1	53
Boulder	40.1	105.2	49
Vandenberg	34.8	120.5	40
Goose Bay	53.3	60.5	63

For the two stations located in the path of totality, Chukuni and Bozeman, the time sequences of the eclipse along the ray paths from 0 to 1000km are shown in Fig. 2(*a*) and 2(*b*). For Chukuni, totality extended almost to 900km, whereas for

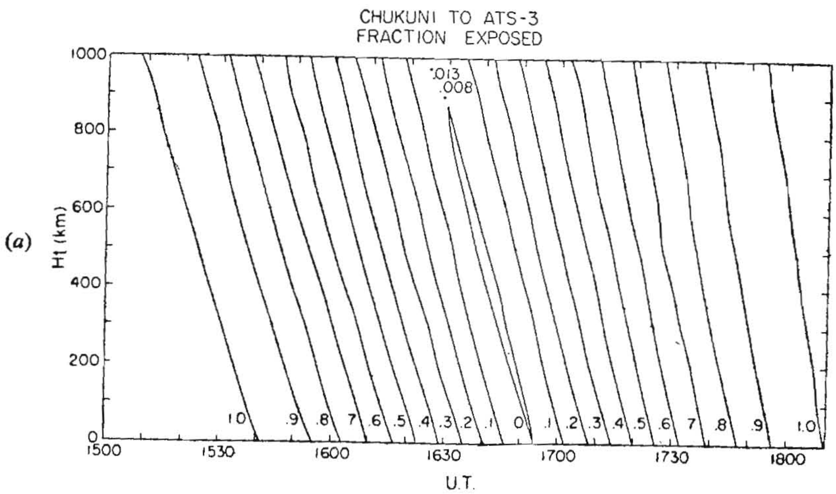


FIG. 2. Time sequences of the fraction exposed of the solar disc during the total solar eclipse of 26 February 1979 along the ray paths from 0 to 1000km for (*a*) Chukuni and (*b*) Bozeman.

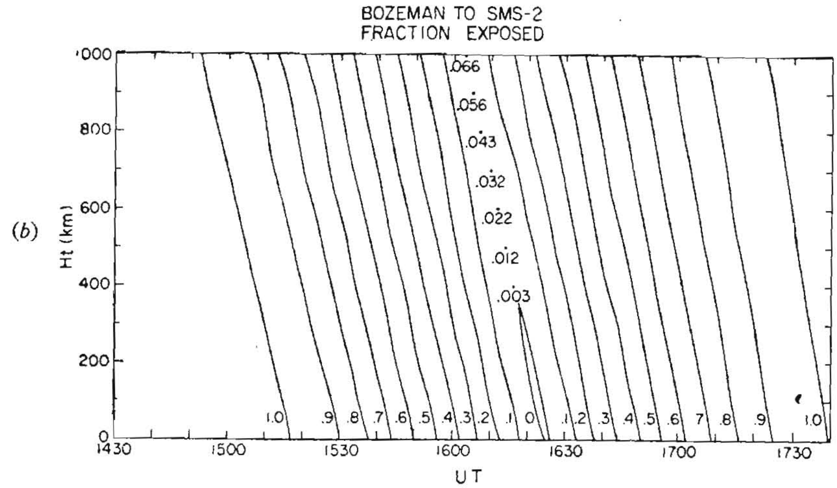


FIG. 2. *(For caption see p. 446)*

Bozeman, it reached almost 400km. For both stations, the contact times occurred at earlier times with increasing height.

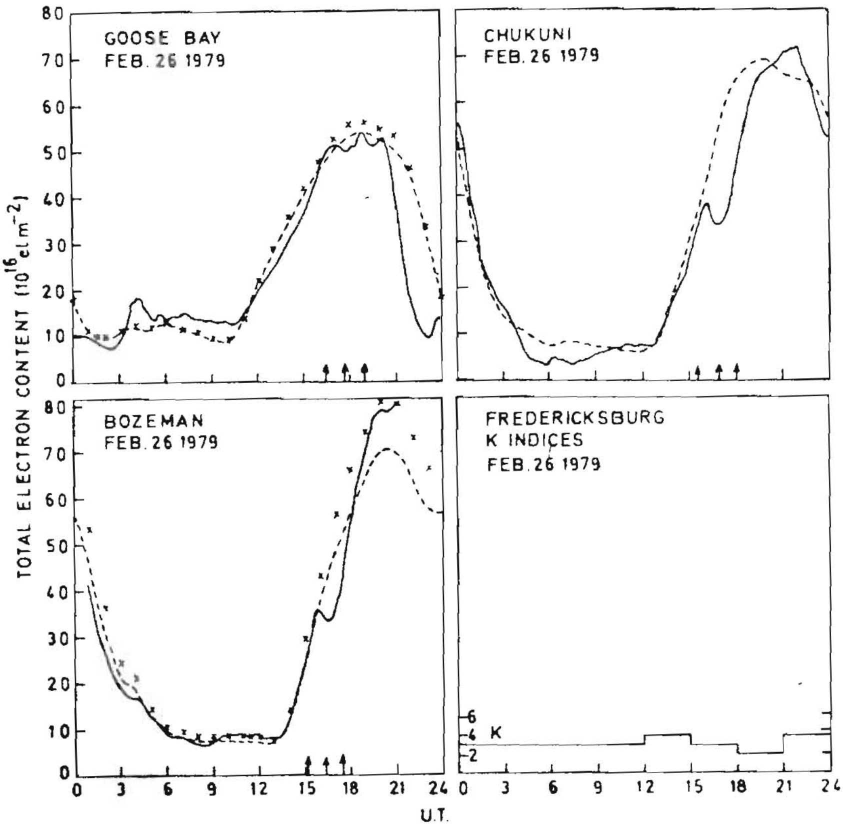
Ionogram data from Fort Monmouth, Boulder, Vandenberg and Goose Bay were also used to investigate the bottomside changes during the eclipse.

RESULTS

(*a*) *Total Electron Content*

Figs. 3(*a*), (*b*) and (*c*) show the TEC results for the eight stations. Also shown in Figs. 3(*a*) are the Fredericksburg K indices for 26 February 1979. A magnetic storm had occurred on 22 February and the day of 26 February was still showing moderate activity. Numerous small substorms were reported from 0845 UT to 1900 UT. For the TEC results shown in Fig. 3, the continuous lines are the results for 26 February, the dashed lines are the average for several days around the eclipse day, and the crosses indicate TEC curves which have been obtained from the averages by normalization at a suitable time to the TEC curves for 26th. This procedure was adopted if the average curves differed markedly from the curves for the eclipse day. Arrows on each plot indicate the time of first contact, maximum obscurations, and last contact of the eclipse at a height of 300km. The eclipse day TEC values were taken at five minute intervals from 14 to 21 hours UT, all other data being taken at fifteen minute intervals. For each station, the average curve was derived from available data, this varied from two to six days around the eclipse day.

The time variation of the eclipse at 300km height for the ray path to the satellite for each observation from the stations together with the deviation of the TEC, ΔN_t, from the average curve (dotted line) and the deviation from the normalized average curve (crosses) are shown in Figs. 4(*a*), (*b*) and (*c*). The rate of change of TEC, dN_t/dt, is also plotted in Fig. 4 together with that of the average curve. The vertical lines indicate the time of first and fourth contacts and the maximum obscuration at 300km. This height was chosen as an intermediate point between that of peak production and that of median height of the Faraday TEC.



(a)

FIG. 3. (a), (b), (c). TEC results for the eclipse day (solid curve) together with the average variation (dashed curve) and normalized average values (crosses) (*see text*) from the various stations. Also shown are the K indices from Fredericksburg for the eclipse day.

For each of the TEC eclipse day results, the time delay of minimum TEC, and of maximum TEC depletion from the time of maximum eclipse were noted. Table II summarizes these results for each station and satellite observed together with the eclipse contact times, per cent maximum eclipse and the TEC per cent depletion. The TEC from all of the stations except Ramey and Goose Bay showed an effect which could be attributed to the eclipse. For the ray path from Ramey, the ionosphere was only 2 per cent eclipsed at 300km at maximum contact and no effect which could be attributed to the eclipse was observed. Goose Bay TEC appeared to be under the influence of particle precipitation in the auroral regions as the effect of the photoionization cut-off was small. Scintillation activity occurred throughout most of the day. For the remaining nine TEC results, first contact commenced at local times ranging from 0632hr at Vandenberg sub-ionospheric point to 1246hr at the Hamilton to SIRIO satellite sub-ionospheric point. Hence, for Vandenberg, Bozeman, Boulder and Chukuni, the eclipse occurred during the morning increase in TEC and thus caused a delay in the morning increase. For the TEC results from Hamilton and Kennedy, the eclipse occurred near the peak of the TEC and hence caused a 'bite out.' However,

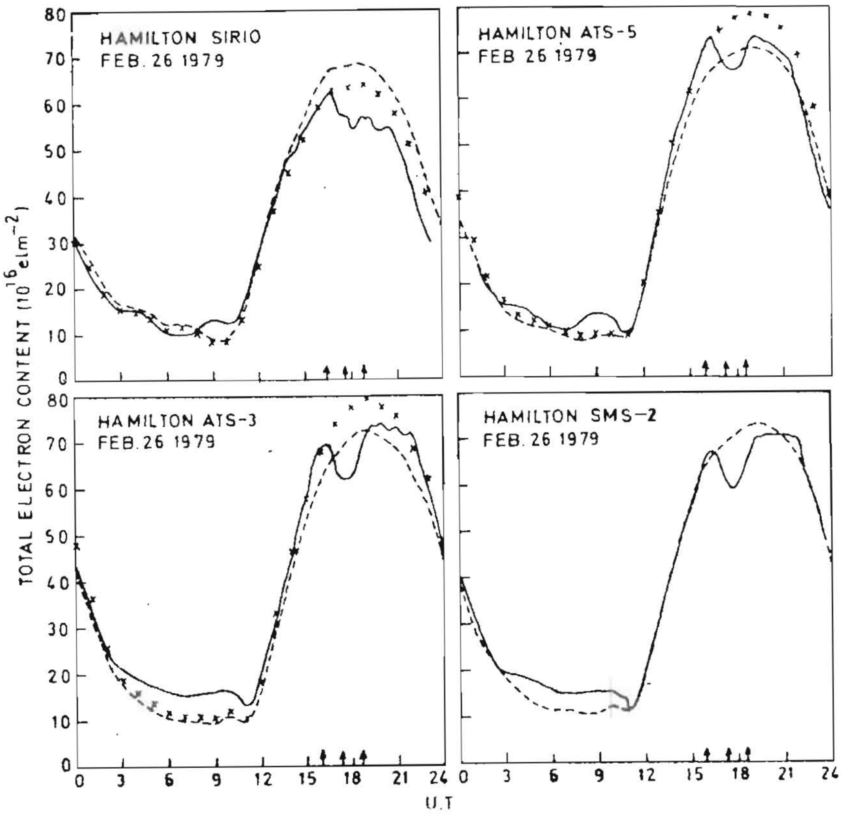


FIG. 3(*b*). *(For caption see p. 448.)*

TABLE II

Station	Satellite	300km First Contact (U.T.)	Maximum (U.T.)	Fourth Contact (U.T.)	% Eclipse	TEC % Depletion	Time delay from maximum eclipse (minutes) Minimum TEC	Maximum TEC Depletion
Goose Bay	ATS-5	1626	1741	1854	71	11	14	14
Chukuni	ATS-5	1530	1645	1804	100	40	5	30
Bozeman	SMS-2	1510	1619	1734	100	38	16	36
Hamilton	ATS-3	1554	1714	1833	64	20	11	46
	SMS-2	1554	1714	1834	67	16	31	31
	SIRIO	1625	1739	1850	47	14	36	36
	ATS-5	1604	1723	1840	59	15	37	37
Boulder	GOES-2	1506	1618	1738	92	29	12	67
Vandenberg	ATS-1	1447	1549	1658	81	39	—	11
Kennedy	ATS-5	1534	1649	1807	39	7	—	26
Ramey	ATS-5	1633	1706	1740	2	0	—	—

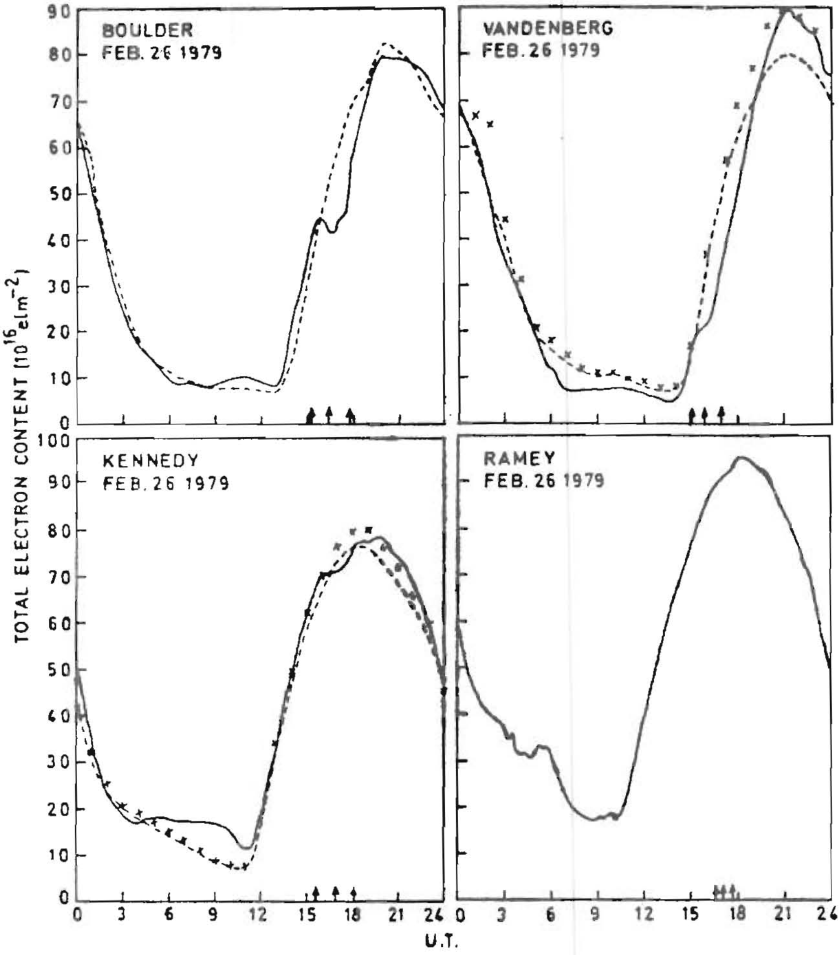
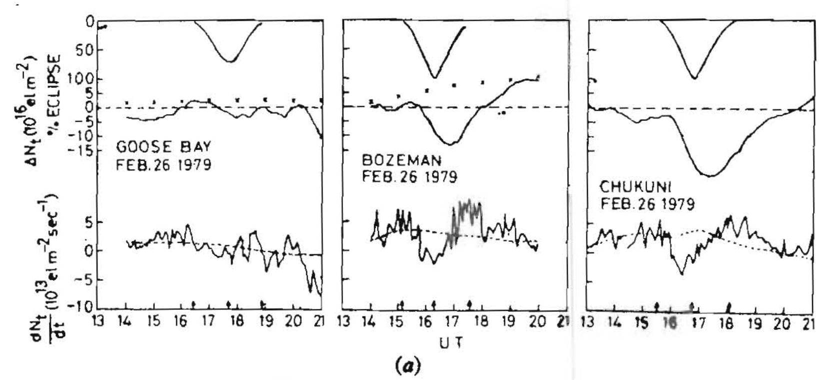


FIG. 3(*c*). (*For caption see p. 448.*)



(*a*)

FIG. 4. (*a*), (*b*), (*c*) Time sequences of the percentage observation at 300km, the change in TEC and the rate of change of TEC for each station except Ramey for the eclipse day (solid lines), the average value (dashed lines) and normalized average values (crosses).

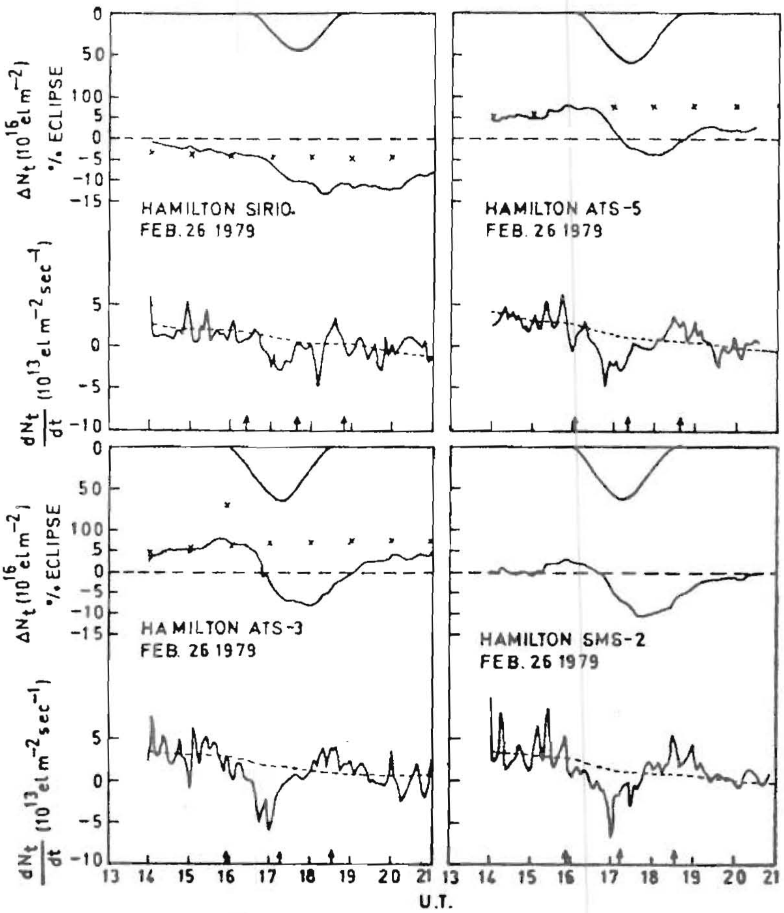


FIG. 4(b). *(For caption see p. 450.)*

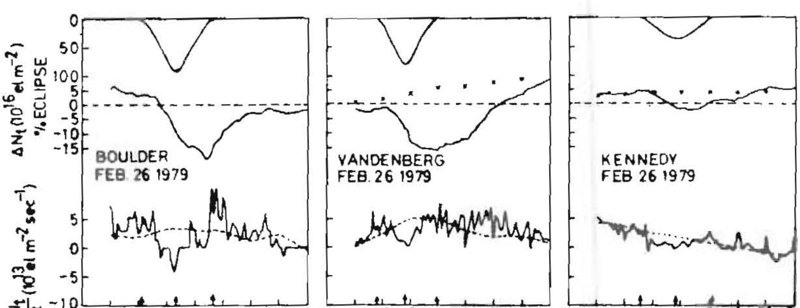


FIG. 4(c). *(For caption see p. 450.)*

for the Hamilton SIRIO satellite results, fourth contact occurred at the expected daily peak time of the TEC and hence, the TEC did not recover from the eclipse depletion before the afternoon decrease commenced (*see* Morton & Essex, 1978).

For the TEC results from Chukuni, the rate of depletion showed a rapid fall after about 30 minutes following first contact, reaching a minimum value before maximum contact. Before fourth contact was reached, the rate of increase of TEC had overshot the non-eclipse average, gradually, returning to the non-eclipse average after the fourth contact. Maximum TEC depletion occurred at 30 minutes after maximum solar observation. This type of behavior was typical of most of the TEC results. Fig. 5 is a plot of the percentage depletion of the TEC results *versus* the percentage

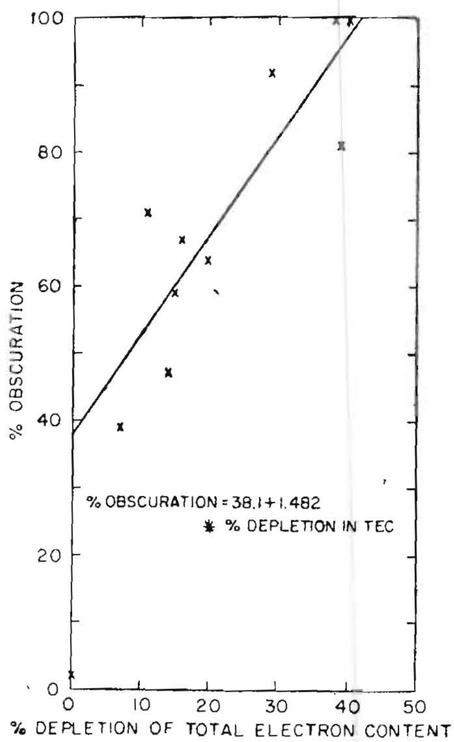


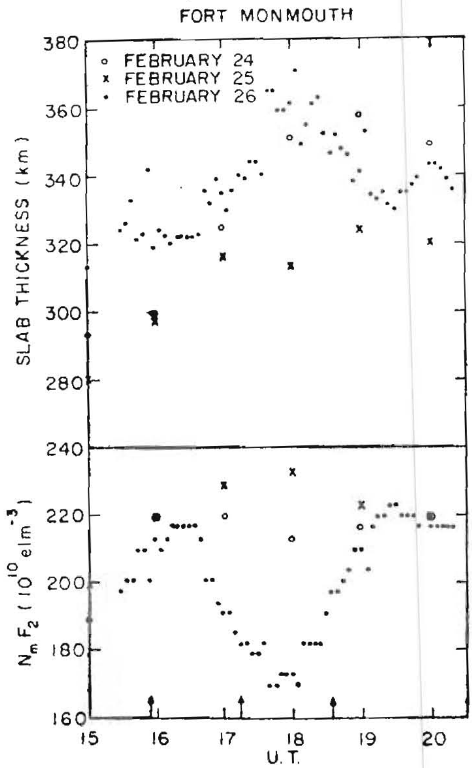
FIG. 5. Graph of the percentage observation *versus* percentage depletion using data from the eleven TEC results. The line of best fit (excluding Ramey TEC data) is % observation = 38.1 + 1.482 + % depletion in TEC.

observation. As a first order approximation, the line of best fit for the points is:

% observation=38.1 + 1.482 + %depletion in TEC. Hence, for this eclipse, no measurable effect occurred in the ionospheric total electron content until the percentage observation of the sun exceeded 38 per cent.

(*b*) *Ionograms*

Ionosonde data from Fort Monmouth, Boulder, Vandenberg and Goose Bay for the eclipse period were analyzed to determine the bottomside response to the eclipse. The peak density of the ionosphere was determined from the f_0F2 values at five minute intervals obtained from the Fort Monmouth ionosonde for the eclipse period on 26 February 1979. The results are shown in Fig. 6(*a*) together with the



(*a*)

FIG. 6. (*a*) Peak density and slab thickness variations at Fort Monmouth during the total solar eclipse of 26 February 1979 (dots at five minute intervals) and on February 24 (circles at hourly intervals) and February 25 (crosses at hourly intervals).
(*b*) and (*c*) Topside and bottomside TEC, peak density, peak height and slab thickness variations at Boulder and Vandenberg during the total solar eclipse of 26 February 1979 (fifteen minute values). Also shown for Boulder are the peak density and slab thickness variations at hourly intervals (crosses) for 25 February 1979 (*see* pp. 454-55).
(*d*) Peak density variations at 10 minute intervals at Goose Bay during the total solar eclipse of 26 February 1979. Also shown are the hourly values for 24 (circles) & 25 (crosses) February 1979. The arrows indicate the first, maximum and fourth contact of the eclipse in the ionosphere at 300km (*see* p. 456).

hourly values for 24 & 25 February 1979. The arrows indicate the eclipse contact times in the ionosphere at 300km. The Fort Monmouth peak density behaviour is very similar to the Hamilton TEC results. In this case, the parts of the ionosphere being sampled are very close (*see* Table I). Slab thicknesses (the ratio of the TEC to the peak density) were calculated using the Hamilton ATS-3 satellite. The slab thickness parameter is a first order measure of the shape of the ionosphere F-region profile. Both the eclipse day and 24 February showed increases around the same UT times. Hence, the slab thickness increases on 26 February are not necessarily the result of the eclipse.

True height reduction of the ionosonde data were carried out for the eclipse period at fifteen minute intervals for Vandenberg and Boulder. From the calculations, the bottomside TEC was obtained and thence the topside TEC by subtraction from the corresponding Faraday TEC recorded at that station. These results are plotted in Fig. 6(*b*) for Boulder, and Fig. 6(*c*) for Vandenberg together with the F-region peak density and height, and slab thicknesses. For Boulder, the peak density and slab

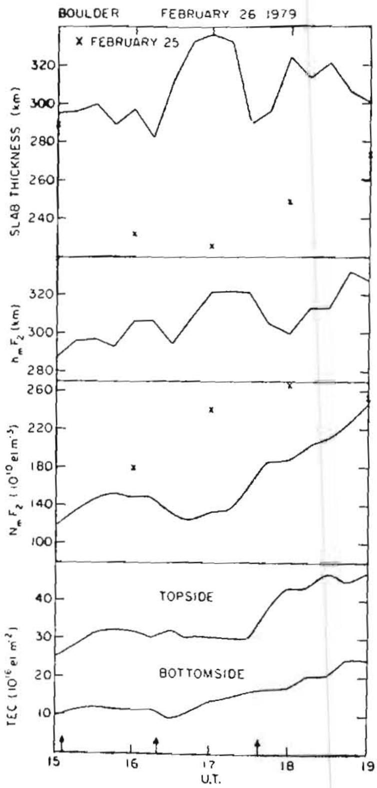


FIG. 6(*b*). *(For caption see p. 453.)*

thickness at hourly intervals on 25 February are also shown. The TEC and ionosonde data do not refer to exactly the same location, but within our limits of accuracy, the contact times of the eclipse are coincident. Comparison of the true height profiles (not shown), the bottomside, and topside TEC and h_m F1 for Boulder indicates that a filling in of the bottomside ionosphere starts after maximum observation whereas the topside TEC does not start to increase for over an hour. This is partly caused by an increase in h_m F2, although the total TEC shows a similar behavior. The slab thickness parameters also shows an increase, indicative of a change in layer shape.

First contact of the eclipse at Vandenberg occurred before the E-layer had formed and hence bottomside observations are complicated by the normal morning formation of the E-layer and its depletion by the eclipse. Large variations in the height of the peak also modify the bottomside TEC results. The slab thickness parameter shows a continuous increase, indicating a change in layer shape. This is indicated on the bottomside by the changes in the true height profiles (not shown) as the E-layer forms.

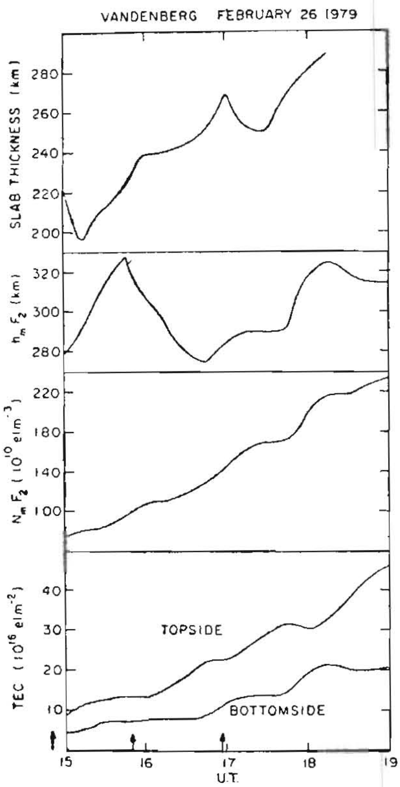


FIG. 6(*c*). (*For caption see p. 453.*)

Fig. 6(*d*) is a plot of N_mF2 at Goose Bay on the eclipse day, 26 February, and on the two previous days, 24 and 25 February. The peak density for the eclipse day is considerably less than that for the two previous days. A decrease in the peak density commences around the time of maximum obscuration and recovery does not start until after the fourth contact. The peak density only recovers a small amount before the late afternoon decrease, which is generally rapid at Goose Bay, occurs. During the duration of the eclipse, the ionosonde data is complicated by the occurrence of a second F2-layer of higher density (*see* Fig. 6 (*d*)) This may be caused by other auroral activity or reflections from a higher density layer further to the south in a region of lower obscuration. The Goose Bay TEC (Fig. 3 (*a*)) shows only a small eclipse effect whereas the Goose Bay peak density which is observed further to the north and hence closer to the peak of totality (*see* Fig. 1) shows a marked eclipse effect.

DISCUSSION

The TEC results presented here for the total solar eclipse of 26 February 1979 across North America show that the cut-off in solar ionizing radiation produced a significant depletion in the TEC along the path of the eclipse. At one of the stations, Goose Bay, the eclipse effect was probably partly masked by particle precipitation associated with substorm events. A first order approximation indicates that for this eclipse, for

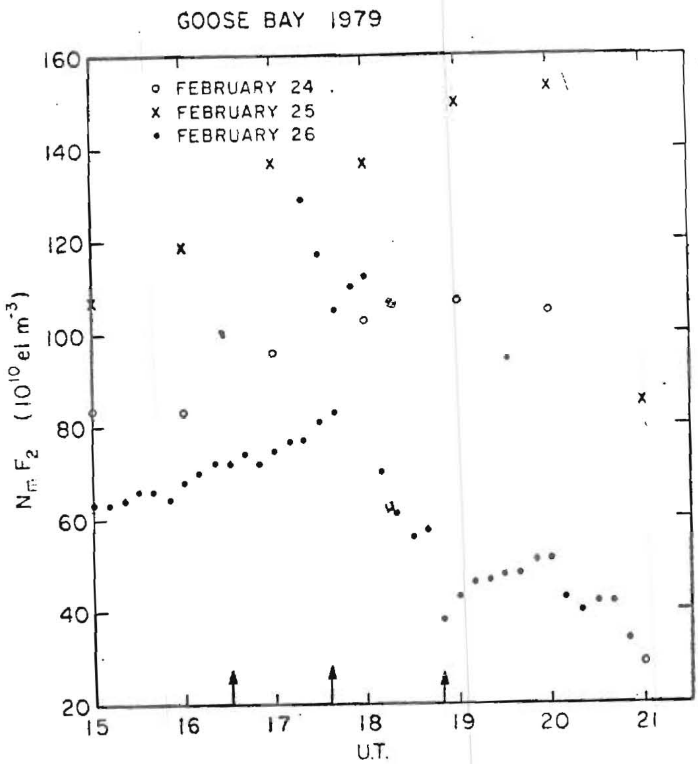


FIG. 6(*d*). (*For caption see p. 453.*)

observations greater than 38 per cent, a depletion in TEC occurred. This effect in TEC is larger than that reported by Almeida *et al.* (1972) and Marriott *et al.* (1972) for the 1970 total solar eclipse across North America. These differences may have been caused by oppositely directed vertical wind drifts during the two eclipses. For the 1979 eclipse the path of totality was northward for all the stations except for the two stations in the path of totality.

One of the interesting features of the TEC results from most of the stations for this eclipse was the recovery of the rate of change of the TEC to values greater than the average non-eclipse values before fourth contact and their slow return to the non-eclipse values after fourth contact. Possible explanations for this effect include the modification of neutral winds and electric fields during the eclipse. This effect requires further investigation.

Investigation of the peak density and bottomside ionosphere using ionosonde data showed that the peak density and TEC depletions were similar for two of the four stations for which data were available. For the third station, Vandenberg, the eclipse commenced early in the morning before the E-layer had formed and the peak density showed only small changes although the TEC results show a large depletion. This result is probably due to the combined effect of large changes in layer height (h_mF2) and shape (slab thickness) (*see* Fig. 6 (*c*)). Increases in slab thicknesses occurred at both Fort Monmouth and Boulder during the eclipse but these changes cannot definitely be attributed to the eclipse as similar variations occurred on other days (*see* Fig. 6 (*a*)). Similar results have been reported by Klobuchar and Malik (1970) during the 1970 total solar eclipse. For the fourth station, Goose Bay, the proximity of the auroral oval and the spatial separation of the parts of the ionosphere being sampled by the ionosonde and the Faraday rotation measurements may have led to differences in the peak density and TEC.

Acknowledgements

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