Communications

vlf Sudden Phase Anomalies during Flares of Aug. 1972*

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Sudden phase anomalies during solar flares of 2 and 4 Aug. 1972 were observed in NPG 18·6 kHz signals over a long vlf propagation path between Jim Creek, Washington and Naini Tal. This and the other simultaneous phase anomaly data by Naito *et al.* [*Solar geophys. Data, UAG*, **28** (1973), 584] at a frequency of 22·3 kHz over a propagation path between Uji, Kyoto University and NWC, Australia, have been utilized to study the enhanced D-layer ionization and lowering of reflection heights during the flares. The values of $\alpha_{eff} = 5{\cdot}5 \times 10^{-5}$ cm^3 sec^{-1} and $2{\cdot}91 \times 10^{-3}$ cm^3 sec^{-1} for the 2 and 4 Aug. 1972 flares are higher than the values estimated by Chakrabarty D K and Mitra A P [*Indian J. Radio Space Phys.*, 3 (1974), 76] for strong flares.

The intense solar flares of 2 and 4 Aug. 1972, of optical importance classes 1B and 3B respectively are responsible for causing sudden phase anomalies (SPA) in very low frequency (vlf) region. The ionizing fluxes at wavelengths 1-3 Å, associated with these flares, are estimated for reasonable values of the effective recombination coefficients in the D-layer. The method of analysis and the notations have largely been patterned after Chilton *et al.*[1]

The equipment[2] used for registering the vlf phases at Naini Tal consists of a quartz crystal oscillator and a superheterodyne receiver with an electronic servo-system for phase tracking. A whip antenna coupled to an impedance transformer is used with the vlf receiver and the output of the vlf receiver is fed directly to a strip chart recorder.

The phase variation records of 2 and 4 Aug. 1972 for the NPG 18·6 kHz signals, transmitted from Jim Creek, Washington (48°12′N; 238°05′E) and received at Naini Tal (29°22′N;79°27′E), were analyzed. Simultaneous phase advance values reported by Naito *et al.*[3] for NWC 22·3 kHz signals, propagating between Australia (21°49′S;114°10′E) and Uji, Japan (34°54′N;135°48′E), have also been utilized.

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The estimated deviations in phase with respect to the average diurnal vlf phase curve for quiet periods are shown in Fig. 1. Using the theory of Chilton *et al.*,[4] the observed phase advances were converted into height change Δh, according to the following expression valid for large distances:

$$\Delta h = -\Delta\phi \frac{h\lambda}{2\pi d}\left[\frac{h}{2a} + \frac{\lambda^2}{16h^2}\right]^{-1}$$

where $\Delta\phi$ is the phase change for the vlf signals in radians; h, the mean height of reflection taken as 80 km; a the mean radius of the earth taken as 6371·2 km; λ, the wavelength of vlf signals in km; and d, the great circle distance between the receiver and the transmitter (in km) measured along the surface of the earth. This distance for NPG signals was taken as 11131 km and that for NWC signals was calculated to be 6710 km.

The average value of the solar zenith angle, ψ_{av}, was obtained using the procedure given by Iizima *et al.*[5] The results of our study are summarized in Table 1 and Fig. 2. The optical sighting times in Table 1 are borrowed from Zirin and Katsuo.[6] Fig. 2 gives a plot of Δh versus sec ψ_{av} and the intercept of the same with the X-axis gives us a change in reflection height of the D-layer at the sub-solar point (sec $\psi = 1$).

Utilizing the sub-solar values of Δh and adopting the approach given in Chilton *et al.*,[1] the values of N_r/N_0, the ratio of the electron density required for reflecting the vlf signal and peak value of electron density for the sub-solar point in the D-layer during

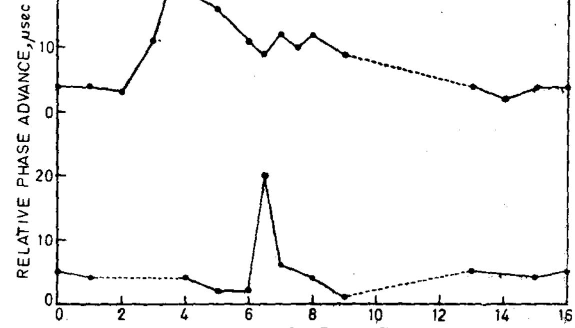

Fig. 1—The relative phase variations of NPG signals observed at Naini Tal

Table 1—vlf Sudden Phase Anomalies during Solar Flares

Date (year: 1972)	Optical importance class	Optical sighting hrs UT	Time of maximum SPA hrs UT	Phase change $\Delta\phi$ in μ sec	Δh km	vlf propagation path	Distance km	ψ_{av} deg.
2 Aug.	1B	0330	0340	21·0	9·3	NWC-Kyoto	6710	17·9
			0335	16·0	3·9	NPG-Naini Tal	11131	59·6
4 Aug.	3B	0620	0633	31·5	13·9	NWC-Kyoto	6710	45·7
			0630	17·5	4·3	NPG-Naini Tal	11131	60·9

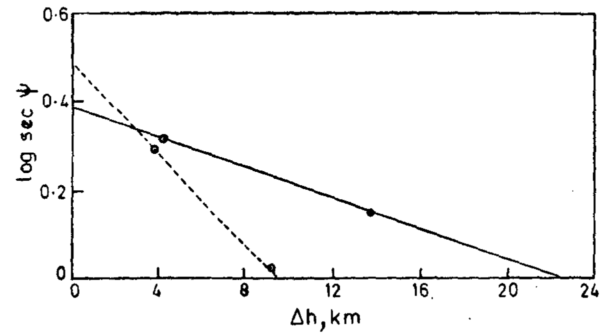

Fig. 2—Experimental observations of log sec ψ versus Δh for the solar flares of 2 Aug. 1972 (broken line) and 4 Aug. 1972 (solid line)

Table 2—Results of Various D-region Parameters Obtained from SPA for the two Flares during 1972

Parameter	2 Aug.	4 Aug.
Flare class	1B	3B
Time hrs U T	0330	0620
N_r/N_e	0·40	0·90
τ_r	4·26	1·79
λ, Å	2·7	1·3
E, keV	4·6	9·53
Δh, km	10·5	21·5
h_0, km	80·3	63·0
h_r, km	69·5	58·5
α_r, cm^3/sec	$5{\cdot}5\times10^{-5}$	$2{\cdot}91\times10^{-3}$
I_∞, ergs/cm^2 sec	$7{\cdot}0\times10^{-3}$	$7{\cdot}46\times10^{-2}$

the flares, were obtained. Further, the wavelength region responsible for the enhanced ionization and lowering of the heights of the D-layer was established to be between 1·3 and 2·7 Å using mass absorption coefficient of X-radiation in air by Forsythe[7] and the neutral atmospheric density model CIRA 65.

For each of the flares the effective recombination coefficient, α_r at the reflecting layer under the sub-solar point was estimated during the course of establishing the wavelengths of the ionizing radiation using the relation:

$$\text{Radiation flux, } I_\infty = \frac{N_r^2\,\alpha_r\,H\exp(\tau_r)}{\eta\,.\,\tau_r}$$

where τ_r is the optical depth; H, the mean scale height for the D-region taken to be 7·5 km; α_r, the effective recombination coefficient; η, the ionizing efficiency which is the composite yield[8] for air of about 1 electron per 34 eV; N_r, the mean electron density of 433 electrons/cm^3, taken from the theoretical model of Chakrabarty and Mitra.[9] Taking I_∞ values based on Solrad 9 and 10 data[10] in the 0·5-3 Å band and substituting the values of other quantities, we obtain the α_r values equal to $5{\cdot}5\times10^{-5}$ cm^3/sec and $2{\cdot}91\times10^{-3}$ cm^3/sec given in Table 2. These values are higher than $\alpha_r = 1{\cdot}3\times10^{-5}$ cm^3/sec at $h_r = 69{\cdot}5$ km and $\alpha_r = 3{\cdot}0\times10^{-4}$ cm^3/sec at $h_r = 58{\cdot}5$ km estimated by Chakrabarty and Mitra[9] for the D-region during strong flares.

The discrepancy between our results and those of Chakrabarty and Mitra,[9] may be due to the fact that our results are based on experimental values, while theirs are from theoretical considerations. Another reason is that our method has inherent limitations in the sense that only two propagation paths are taken. The results are, therefore, quite sensitive to the slope of the straight line.

Further, from Table 2 we note that the effective recombination coefficient varies with the optical importance class of the flare.

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