

Some Studies on Long Wave Propagation & Other SID Effects

MANGAL SAIN & S N ROY CHOWDHURY

Research Department, All India Radio, New Delhi

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Continuous recordings of received skywave field-strength from Radio Tashkent (164 kHz, 41° 25' N; 69° 12' E; 1634 km from Delhi) have been going on for the past 20 years in the Research Department of All India Radio. Analysis of the data has shown that a sudden change in amplitude of the received If signal (abbreviated as SCL) is almost always associated with the occurrence of solar flare. Using the field strength data, certain parameters of lower ionosphere like reflection height from sunrise effect and recombination coefficient from the post-flare variation of If signal, have been evaluated. Some further studies of lower ionosphere using SID effects, SCL and X-ray flare data, have revealed that the effective X-ray region responsible for causing the different types of SCL and other SID effects like SPA and SCNA lies within 1-2 Å and a flux energy of 10^{-3} to 10^{-4} erg cm⁻² sec⁻¹. Analysis of SCNA data at 18 and 29 MHz has indicated that the height of maximum absorption is around 68 km. An attempt has also been made to explain the occurrence of different types of SCLs vis-a-vis the nature of X-ray flares.

1. Introduction

The Research Department of All India Radio became involved in the investigation of long wave propagation in 1958 while carrying out measurements on absorption by A-1 technique¹ and developed a simple, precise and reliable radio-method of detecting solar flares through the continuous recording at Delhi of sky wave field strength of Radio Tashkent (69° 12' E; 41° 25' N) operating on 164 kHz and situated at a distance of 1630 km. It has been observed that whenever there is a flare on the sun, there is a simultaneous sudden change in the amplitude of received long wave signal abbreviated as SCL. Most of the SCLs have been found to correlate well with flares reported.²⁻⁴ In general, three types of flares, namely, A, B and C have been observed.

In this paper, SCL and other SID (sudden ionospheric disturbance) data have been used to study certain parameters of the lower ionosphere. An attempt has also been made to explain the occurrence of three types of SCLs.

2. Evaluation of Reflection Height and the Recombination Coefficient of Lower Ionosphere

2.1 Evaluation of Reflection Height from Sunrise Effect

The sunrise time for the period June 1965 to May 1966 has been used to calculate the reflection height at control point of the propagation path between Delhi and Tashkent.

This height has been found to be between 65 and 75 km in summer whereas in winter and equinox

it has been found to be around 75 km (Ref. 4). The height of reflection during the IGY has been found to be 65 km during summer and 75 km during winter.⁵ The average height can be taken to be around 70 km.

2.2 Evaluation of Recombination Coefficient (α)

During the solar flare, the ionization in the absorbing region is enhanced considerably depending upon the flare intensity. At maximum of the flare, when no further ionization takes place due to flare radiation, the enhanced ionization decays gradually to the normal value at a rate depending upon the coefficient of recombination and electron density. Using the continuity equation of Appleton and Piggott,⁶ it has been possible to find the value of α using the SCL data collected during the years 1966-68. The mean value of α works out to be 2.4×10^{-6} cm³ sec⁻¹, which agrees with the value obtained by Mitra² for a layer height around 70 km.

2.3 Other Studies of Lower Ionosphere Using SID Effects, SCL and X-ray Flare Data

2.3.1 Earlier work—Figs. 1(a) to 1(c) show X-ray flare observed on 13 Apr. 1966 between 0706 and 0716 hrs UT and simultaneous occurrence of SID effects like SCL on 164 kHz, at Delhi, SNB (sudden noise burst) at 204 MHz at Izmiran, SEA (sudden enhancement in atmospherics) at Ondrejov, SWF (short wave fade out) at Okinawa, SCNA (sudden cosmic noise absorption) at 18 and 29 MHz at Manila and Ondrejov, respectively, and SPA (sudden

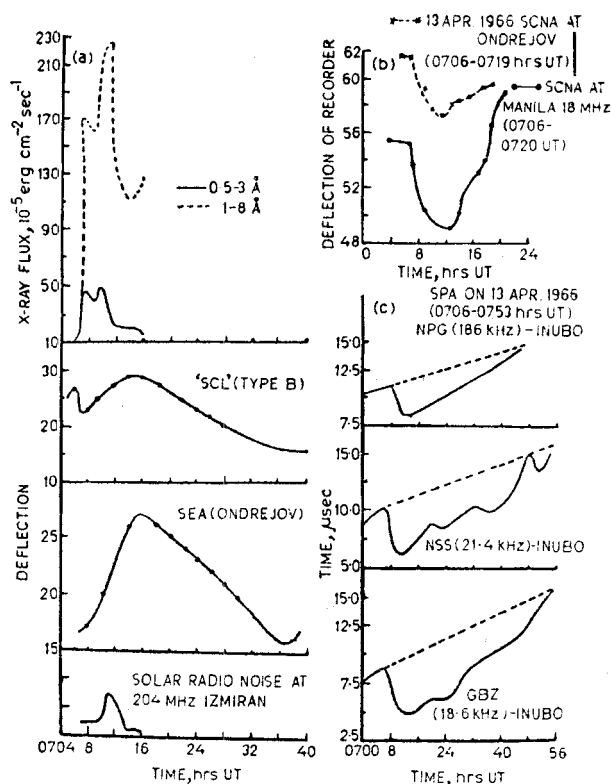


Fig. 1 — Plots showing : (a) X-ray flare observed on 13 Apr. 1966 between 0706 and 0716 hrs UT and some corresponding SID effects; (b) SCNA on 18 and 29 MHz; and (c) SPA observed on different circuits

phase anomaly at Inubo (Japan). These data together with corresponding X-ray flux data collected through solar radiation from the American Satellite, Explorer-30, have been used to study D-region as given below.⁴

From the X-ray flux data at the maximum of flare observed on 13 Apr. 1966, the $N-h$ profiles based on Pierce and Arnold⁷ and Mitra⁸ models of effective recombination coefficients, have been computed for X value 30° (corresponding to reflection point of the long wave signal from Radio Tashkent), 50° (Manila) and 60° (Ondrejov) and these are shown in Fig. 2. These profiles, apart from giving the state of ionization during the occurrence of an SCL, can also be used to find the ionospheric absorption as given below.

The integrated value of absorption at 18 and 29 MHz have been theoretically calculated at the maximum of flares on 13 Apr. 1966 knowing the specific absorption at different heights from $N-h$ profile of the lower ionosphere as computed above. These values have been compared with observed values obtained from Manila (Phillipines) at 18 MHz and Ondrejov (Czechoslovakia) at 29 MHz. The results are shown in Table 1.

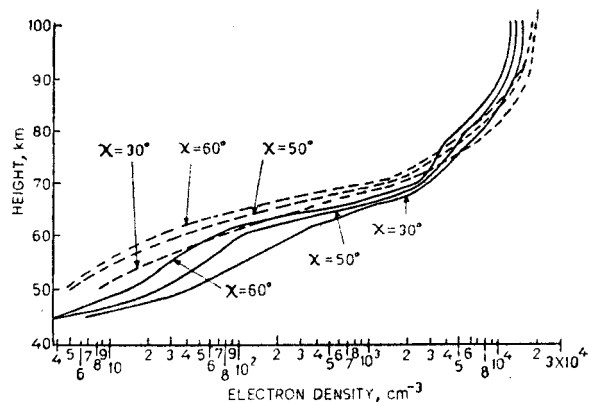


Fig. 2 — Variation of electron density with height [—, after Mitra (1965) model; ---, after Pierce and Arnold (1963) model]

Table 1 — Values of Absorption during the Maximum of Flare on 13 Apr. 1966

Model used	Absorption (in dB) for	
	18 MHz	29 MHz
Pierce and Arnold (1963)	1.60	0.62
Mitra (1965)	1.40	0.51
Observed values	1.00	0.40

It may be seen from Table 1 that the observed values of absorption are somewhat lower than the calculated ones. This may be due to slight difference in the values of α or the collisional frequency models assumed in the calculations. It has also been found that the maximum absorption occurred around 68 km on both the frequencies (18 and 29 MHz).

From the study of SPA and corresponding X-ray flare on 13 Apr. 1966 (Ref. 9) the height of maximum electron production and that of reflection have been worked out to be 66 and 60 km, respectively. The value of N_r/N_0 is calculated to be 0.75 where N_r is electron density at height of reflection and N_0 is the maximum electron density. Assuming Chapman layer formed in lower D-region during a SID¹⁰ the effective X-ray region responsible for this SPA has been found to be around 2 Å and the corresponding flux energy about $10^{-4} \text{ erg cm}^{-2} \text{ sec}^{-1}$, which is in good agreement with measured value of flux during the flare. The results show that X-ray flux intensities may be computed with reasonable accuracy.

An analysis of data of some X-ray flare observed during 1966 (Ref. 4) has shown that for SCL and other SID effects to occur, X-ray flux in the range 0.5 to 8 Å is important with its threshold value varying from 10^{-3} to $10^{-4} \text{ erg cm}^{-2} \text{ sec}^{-1}$ in 0.5 to 2 Å range.

2.3.2 *Recent work* — Mitra¹¹ has reported that, by and large, three types of flares, viz. A, B and C have been found to occur. In case of type A the received signal would increase suddenly and then decrease gradually; for type B sudden decrease in signal would be followed by an increase and then gradual decay; and for type C the signal would suddenly decrease and then would slowly return to normal. There can be complicated types of SCLs having a mixture of these types. It has been indicated in the preceding paragraph that X-rays in the frequency range of 0.5 to 2 Å with a certain minimum value of hardness are responsible for the occurrence of different types of SCLs. However, the reasons for the occurrence of different types of SCLs are not precisely known.

To study the problem further spectral analysis to compute the flux energy for each wavelength has been attempted. Some recent SCLs, which mostly occurred during 1978 (a period of moderately higher sunspot activity), have been selected

for the purpose. The corresponding X-ray flare data in the ranges 0.5-3 and 1-8 Å have been obtained from World Data Centre A. In these cases, single temperature model adopted by Dere *et al.*¹² has been utilized for both the wavelength ranges. This model can be used advantageously except for outstanding events where use of two-temperature model after Deshpande and Mitra¹⁴ may yield more accurate results.

By and large it has been found that the effect of X-rays in the wavelength range of 3 Å and above is insignificant below 70 km to cause any type of SCL. Table 2 shows the different types of SCLs with the corresponding value of X-ray flux in the wavelength range 1-2 Å.

Fig. 3 shows the normal and peak flare time *N-h* profiles drawn for certain cases indicated in Table 2. In working out peak flare time profiles the suitable flare time models of effective recombination coefficient depending upon the hardness of X-ray flare and actual temperature of sun at the maximum of

Table 2 — X-ray Flux in the Range 1-2 Å for Different Types of SCLs

Date and time (in hrs UT)	Integrated X-ray energy in the band (in ergs/cm ² /sec)		Ratio of energy in the bands $R(T) = \frac{E(0.5-3 \text{ Å})}{E(1-8 \text{ Å})}$	Predicted equi- valent temp. of sun °K	Energy (in erg/cm ² /sec) considering the actual radiation condition in 1-2 Å band	Correspond- ing SCL type observed in 164 kHz channel at Delhi	Remarks
	0.5-3 Å	1-8 Å					
1968							
30* Jan. (0505.5)	202×10^{-4}	560×10^{-3}	3.6×10^{-3}	Two temp. model used	7×10^{-3}	B	<i>N-h</i> Profile drawn
1978							
10 Apr. (0530)	6×10^{-4}	1×10^{-3}	3×10^{-3}	13.5×10^6	1.29×10^{-4}	C	do
5 May (1015)	14×10^{-4}	100×10^{-3}	1.4×10^{-3}	10.03×10^6	1.1×10^{-4}	B	do
22 May (0210)	6×10^{-4}	2×10^{-3}	3×10^{-3}	13.5×10^6	1.29×10^{-4}	C	—
5 June (0230)	1.6×10^{-4}	8×10^{-3}	2×10^{-3}	5.7×10^6	6.99×10^{-7}	C	—
1 July (0110)	1.7×10^{-5}	3×10^{-3}	0.57×10^{-3}	7.51×10^6	0.41×10^{-6}	A	<i>N-h</i> Profile drawn
9 July (0715)	1×10^{-3}	3.5×10^{-3}	2.86×10^{-3}	13.2×10^6	1.59×10^{-4}	A	—
9 July (1240)	2.5×10^{-3}	1×10^{-1}	2.5×10^{-3}	12.48×10^6	3.56×10^{-4}	A	—
10 July (0140)	1×10^{-3}	1.1×10^{-1}	9.09×10^{-2}	24.75×10^6	2.90×10^{-3}	B	—
11 July (0545)	2×10^{-3}	2×10^{-1}	1×10^{-1}	26.9×10^6	6.03×10^{-3}	A	<i>N-h</i> Profile drawn
18 July (0900)	1.1×10^{-3}	1.9×10^{-2}	5.7×10^{-2}	18.3×10^6	2.64×10^{-4}	A	do

* Analysis for 30 Jan. 1968 SCL was obtained from the work of Deshpande and Mitra.¹³

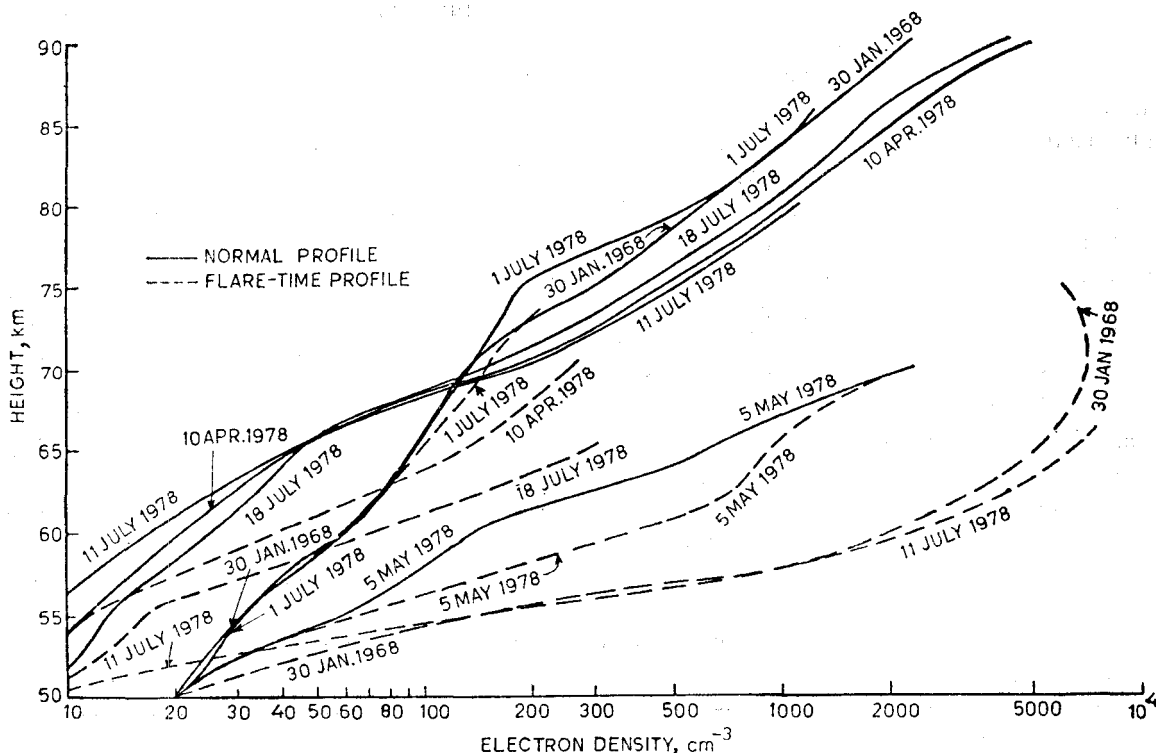


Fig. 3 — N - h profiles for SCLs due to X-rays ($1\text{--}2\text{\AA}$) [1, 11 and 18 July 1978 curves belong to type A; 30 Jan. 1968 and 5 May 1978 curves belong to type B; and 10 Apr. 1978 curves belong to type C]

flare have been utilized after Deshpande and Mitra¹⁴ and Mitra,¹⁵ whereas for normal time profiles, the value of recombination coefficient has been taken after Deshpande and Mitra.¹⁴

In other cases of SCLs depending upon the type shown in Table 2, the N - h profiles are more or less similar to the profiles given in Fig. 3. It may be noted that during X-ray flares of particular hardness in the wavelength range $1\text{--}2\text{\AA}$ (around $1.5\text{\AA}$) a certain type of SCL has been observed. In general, the resultant effect on If signal from a distant transmitter (Radio Tashkent-164 kHz at a distant of 1640 km from Delhi in this case) is the difference in increase in signal due to lowering of height of reflection below the normal height around 70 km and the additional absorption suffered by the signal due to possible increase in collisional frequency and electron density at height below the reflection point. However, the cases of different types of SCLs are explained below.

For the type A cases considered in the Fig. 3 X-ray flux energy and hardness factor (ratio of $0.5\text{--}3\text{\AA}$ to $1\text{--}8\text{\AA}$ flux) corresponding to $1\text{--}2\text{\AA}$, have ranged from 0.41×10^{-6} to 6.03×10^{-3} erg cm⁻² sec⁻¹ and from 0.57×10^{-2} to 1×10^{-1} , respectively. The ionization density responsible to cause reflection of long wave signal in normal ionosphere works

out to be about $150\text{ electrons cm}^{-3}$. In all these cases, lowering of the height of reflection during an X-ray flare by a few km (Fig. 3), and reduced absorption of long wave signal due to its passing through lesser depth of lower ionosphere before reflection, appears to be the probable reason.

In the two B-type of SCLs considered for Fig. 3, the flux energy and hardness factor $R(T)$ corresponding to $1\text{--}2\text{\AA}$ have ranged from 7×10^{-3} to 1.1×10^{-4} erg cm⁻² sec⁻¹ and from 3.6×10^{-2} to 1.4×10^{-2} , respectively. The N - h profiles (Fig. 3) for these SCLs show that at the beginning of X-ray flare there is no significant change in the height of reflection of long wave signal, but due to increase in the electron density at lower height, the signal is attenuated due to enhanced absorption and as the X-ray flare progresses the electron density further increases, thus lowering the height of reflection and consequently increasing the overall signal intensity as in the case of A-type of SCLs. Thereafter, as the conditions normalize, the long wave signal gradually becomes normal depending upon the recombination coefficient, etc.

In the case of C-type of SCL considered in Fig. 3, the hardness factor and X-ray flux energy are 3×10^{-2} and 1.29×10^{-4} erg cm⁻² sec⁻¹, respectively, in the wavelength range of $1\text{--}2\text{\AA}$. Normal

and peak flare time profiles shown in Fig. 3 indicate that fall in signal due to excessive absorption in the lower layer exceeds the increase in signal due to lowering of height of reflection, taking an electron density of about $150 \text{ electrons cm}^{-3}$ sufficient to reflect the long wave signal under normal conditions.

It may be interesting to note that during an X-ray flare, the electron detachment coefficient (γ) (Ref. 16) from negative ion is a varying factor and is quite significant in controlling the effective recombination coefficient, and hence the N - h profile at the lower heights. Accordingly, the type of SCL is likely to depend on value of γ which contributes significantly to the absorption of long wave signals at lower heights.¹⁷

3. Conclusions

The average height of reflection of long wave signal from Radio Tashkent works out to be about 70 km. The maximum absorption of short wave signal, at 18 and 29 MHz has been found to take place around 68 km. In case of SPA (for this case), the height of maximum electron production is around 66 km, whereas the height of reflection is about 60 km. It has also been found that effective X-ray region responsible to cause the different types of SCLs and other SID effects like SPA and SCNA is around $1\text{--}2 \text{ \AA}$ corresponding generally to a flux energy of 10^{-3} to $10^{-4} \text{ erg cm}^{-2} \text{ sec}^{-1}$. It is also observed that X-ray hardness factor (ratio of $0.5\text{--}3.0 \text{ \AA}$ to $1\text{--}8 \text{ \AA}$ flux) and γ , the electron detachment coefficient of negative ions, are also quite important to explain the occurrence of different types of SCLs. However, a very comprehensive analysis of X-ray flare data vis-a-vis SCLs, considering the preflare condition of ionosphere, changes in its chemical composition, temporal and seasonal effects, is needed to explain precisely the occurrence of different types of SCLs or any other SID effects.

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