Studies on VLF propagation in relation to solar and geo-physical events

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ABSTRACTS:

The regular amplitude of the 19.8 kHz VLF signal shows the sunrise and sunset effects, variation of the amplitude in different months. The signal level also varies with the four solar phases of a year. The Four solar phases are Phase1 (June 21 to September 21), Phase2 (September 22 to December 21), Phase3 (December 22 to March 21), Phase4 (March 22 to June 20). From the diurnal and seasonal behaviour it has been found that the signal level is higher in the evening and post evening hour than the daytime. The daily maximum and minimum values of the amplitude (in dB above 1 μV) are also found to vary with different seasons and different local hours. We also studied the correlation between the NWC signal amplitude and the solar 10.7-cm.-radio flux & geomagnetic storm effect.

INTRODUCTION:

The VLF spectrum (3 kHz to 30 kHz) offers many interesting monitoring possibilities due to its unique characteristics. When transmitted, these frequencies travel in powerful wave fronts that follow a "trough" formed between the earth's ionosphere and its surface. These waves follow the contour of the earth's crust and ocean's surface very closely and actually penetrate to distances below both. Considering the normal electron density profile, the daytime and nighttime ionospheric reflection heights are 70 and 90 km respectively for VLF and LF radio waves. Any short time or long time variations in the electron densities at those regions appear as the signature in the amplitude of the VLF and LF radio waves. Because of small electron densities and high electron-neutral molecule collision frequencies, the D region cannot be studied by conventional ionosonde. Studies have been made over a three-year period from March 1996 to February 1999 on an approximately south-north propagation of a long distant (5700 km) radio wave at 19.8 kHz from North West Cape, Australia to Kolkata. Besides ionospheric effects, the seasonal variations of the amplitude of the received signal have been carefully examined in this paper.

EXPERIMENTAL SETUP:

Transmitter: The VLF 19.8 kHz radio wave (call sign: NWC) modulated by 1 Hz, transmitted from North West Cape (NWC), Australia continuously and the estimated power of radiation is 1 MW.

Receiver: The amplitude recording has been done through the amplification of e.m.f. induced in a tuned loop aerial. Simple block diagram of the receiver is shown in Fig. 1. The signal amplifier has been designed using the high slew-rate OP-AMP 531 whereas the DC amplifier contains the OP-AMP 741. The output of the A.C amplifier is detected with a time constant of 0.22 sec. The D.C level is further amplified quasi-logarithmically. The D.C. gain has been used to adjust the receiver's sensitivity corresponding to the incoming signal, which shows marked variation over the year. D.C output is used as the signature of amplitude of 22.3 kHz signal. The maximum gain of the receiver is 120 dB and the overall bandwidth is 200 Hz. The recording chart speed has been adjusted to 2 cm/hr with a time constant of 7.5 s.

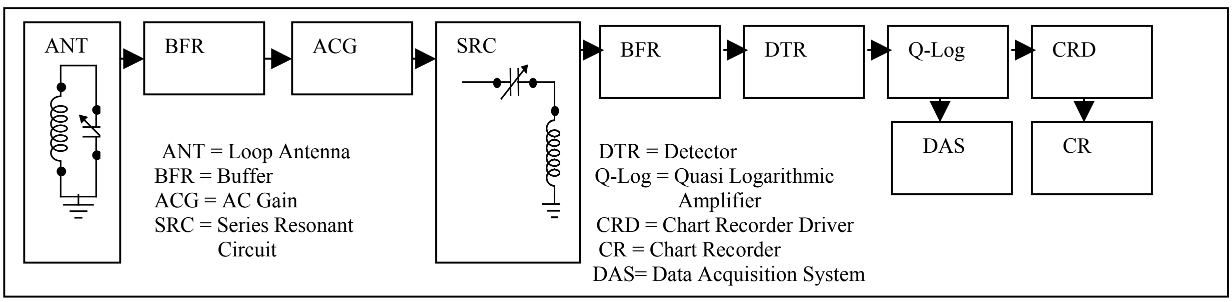

Fig. 1. Block diagram of 19.8-kHz receiver

Propagation path: The great circle path between North West Cape ($22^{0}49^{/}$ S, $114^{0}23^{/}$ E.) and Kolkata (22^{0} $34^{/}$ N, 88^{0} $24^{/}$ E) is 5.7 Mm. From the ray point of view, wave hop three is dominant for the propagation over this large distance. The latitude and longitude of first and second ground refection points are ($7^{0}41^{/}$ S, $105^{0}35^{/}$ E) and ($7^{0}17^{/}$N, 97^{0}E) respectively. The latitude and longitude of first, second and third ionospheric reflection points are ($11^{0}28^{/}$ S, $107^{0}43^{/}$ E), (7^{0} S, $101^{0}16^{/}$ E) and ($11^{0}14^{/}$ N, $94^{0}49^{/}$ E) respectively.

OBSERVATION AND RESULT:

(i) Diurnal behaviour:

The field strength of 19.8 kHz signal has been measured round the clock for a period of three years from March 1996 to February 1999, except the periods of local power failure and some maintenance period. A typical photograph of the chart recorder is shown in the figure below. The sunrise and the sunset effects on the VLF signal are evident in the record. The ordinate represents the induced e.m.f. at the receiver input in dB above 1 μV and the abscissa represents the partial time (in IST) of a whole day, which shows average nighttime signal level is larger than the daytime level. The signal amplitude fades out gradually as the sunrise occurs at the ionospheric reflection zones. After the sunrise fade the signal amplitude rises gradually and attains the largest value in the local evening and post evening hours.

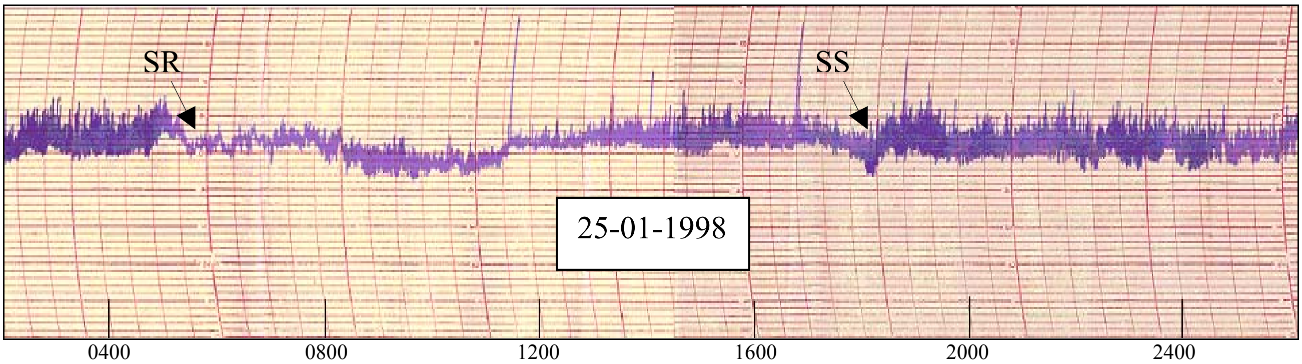

Fig. 2: Diurnal variation of 19.8-kHz VLF signal. The ordinate represents the induced voltage in dB above 1 μV and the abscissa represents the time in hour (IST). [SR= Sunrise, SS= Sunset].

(ii) Seasonal behaviour:

The mean of median of the hourly values of the signal amplitude for different months from March 1996 to February1999 for the three year period has been drawn in the fig. 3. From February to August, the afternoon value of

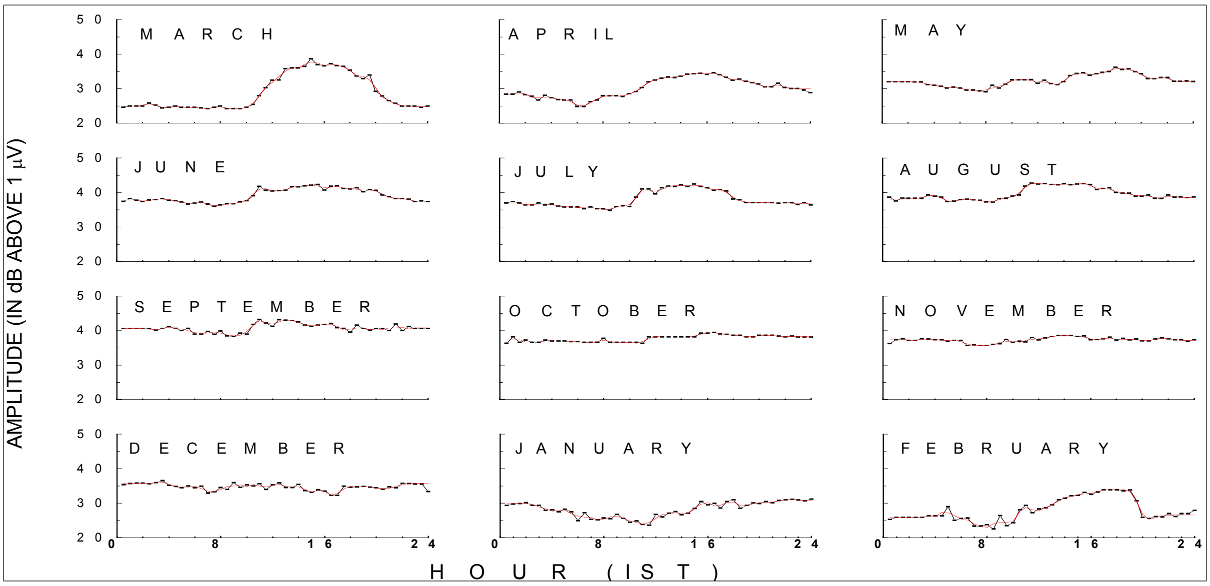

Fig.3: Monthly variation of the signal level

signal strength is remarkably greater than other periods. The afternoon level in September is slightly greater than that in other periods. During October, November and December day-night variation is very small. In January nighttime level is greater than daytime level.

(iii)Variation with Solar Phases:

The seasonal effect on VLF propagation can be analyzed by subdividing the whole year into different solar phases. Fig. 4a is for mean of median values together with the upper and the lower deciles for three year period.

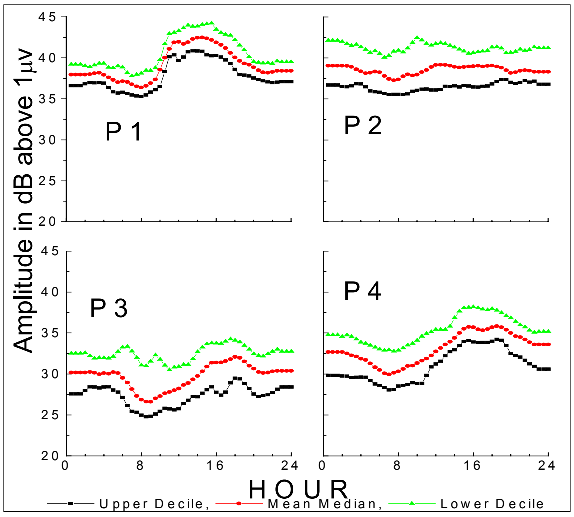

Fig.4a: Mean median with deciles

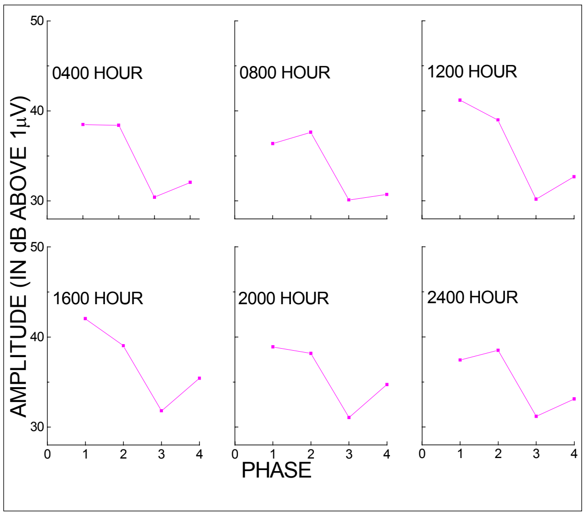

Fig.4b: Amplitude of the signal in different Phases for six discrete hours

In Fig.4b, the amplitude of the signal in different Phases for the six discrete local hours has been plotted. All the graphs are very similar to each other. In all the local hours the amplitude is minimum in the Phase 3 and maximum at the Phase 1 except the 0800 & 2400 hour, where maximum is at the Phase 2. But there is a clear indication that the amplitude of the signal strength is high in Phase1 and Phase2 than the Phase3 and Phase4. In both the figures the ordinate represents the amplitude in dB above 1 µV, whereas the abscissa represents the time in hour (IST).

(iv) Geomagnetic Storm Effect:

In order to study the correlation between the VLF signal strength and geomagnetic activity index we have considered the storm days having A_p>20. During the period of observations we got 95 days having A_p>20. Out of them 59 days have been considered as per our observational days.

Table 1: Correlation co-efficient of NWC w.r.t. Geomagnetic A_p>20 index in different four solar phases

Phse	Correlation Co-efficient in local hours					
	0400	0800	1200	1600	2000	2400
1	-0.22327	-0.23776	-0.09564	-0.21504	-0.05485	-0.27478
2	-0.12833	-0.11680	+0.03327	+0.01423	-0.08831	-0.20513
3	-0.15215	+0.12005	-0.15339	-0.18438	-0.09055	+0.03259
4	-0.55128	-0.26388	-0.09766	-0.21916	+0.02730	-0.08783
Average	-0.26373	-0.18462	-0.078355	-0.151087	-0.06525	-0.082505

Average correlation for Phase			
1	2	3	4
-0.1835566	-0.097678	-0.082168	-0.20785

The above table ascertains a negative correlation that between NWC signal amplitude and the geomagnetic A_p index. The maximum magnitude is 55% in Phase4 at 0400 hr. The correlation co-efficient is dependent upon both time and solar phase. The average of the correlation coefficient of four phases is higher about 20% at 0400 & 0800 hr. and negligible in all other time of the day. If average of correlation coefficient of various times is considered it is around 20% in Phase1 and Phase4 and very small in other two phases. The dawn and morning time exhibit small attenuation associated with magnetic activity index. During magnetically active days ionization at around 70 km height increases by 10 times (Dickinson et al. 1978). This excess electron density plays certain amount of significant role during sunrise transition period and continues up to late morning [1, 2].

(v) Solar 2800 MHz:

We also studied the correlation between the NWC signal amplitude and the solar 10.7-cm. radio flux for the three-year period. We considered the peak days as zero days and preceding and following days are referred as positive and negative days respectively. We found 26 prominent peaks having peak values > 75 for the three years period. The solar flux is in 10^{-22} $Wm^{-2}Hz^{-1}$. But we are to consider only 17 Peaks according to the availability of the NWC 19.8 data. Out of 17 cases, we found that positive correlation occurs for 9 cases whereas negative for 8 cases. It has been observed that the average correlation is about 20% in the phase 1 and Phase 4. The correlation is negligible in the Phase 2 and in Phase3, of the order of 5%. The correlation is positive only in Phase 1, but negative for all other phases.

DISCUSSION:

The general features of the diurnal as well as seasonal variation can be described by wave guide mode theory. These can be accounted by mode conversion and interference between them. A change of wave guide height is responsible for the inter-conversion of the first and second order mode and interference between them. Such modal conversion is mainly due to the position of the sunrise terminator on the propagation path [3, 4]. The seasonal variation of the daily minima is due to the variation of sunrise terminator with relative position of the sun. It is well established that the ionospheric enhancement of electron density took place in the altitude range 68 to 90 km [5, 8]. Again in Phase1and in Phase4 solar rays are mostly inclined, in the Phase3 and in Phase 4 mostly vertical, in the southern hemisphere, which may cause the negative correlation between NWC 19.8-kHz and geomagnetic storm effect in Phase1 and Phase4 around 20%. It has been observed that the day to day variation of the solar 2800 MHz does not follow the 19.8-kHz signal. Though the ionospheric level is controlled by solar activity, such long distance VLF propagation does not follow ionospheric conditions may be due to superposed effects of other geophysical events [9, 10]. From the analysis we may conclude that the solar 2800 MHz cannot be used as an index for long distance VLF propagation.

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REFERENCES:

[1] J.W.King, J.L.Fooks, "Long Lasting Storm Effect in the IonosphereD-Region", *J. atmos. terrest phy.,* **30,** 639-643, 1968.
[2] P.H.G.Dickinson, F.D.G.Bennett, "Diurnal Variations in the D region During a Storm After-Effect", *J. atmos. terrest phys.*, **40**, 549-558, 1978.
[3] H.P.Joshi and K.N.Iyer. *J atmos terrest phys*., **50**,507, 1988
[4] K.R.Pandya, K.N.Iyer, J,K.Sandya and R.K.Rai. *Ind.J. Rad.Space.Phys*.**22,** 374, 1993
[5] J. Courchley and Z. Rahmani , "Phase and amplitude variations of 40 kHz radio waves propagating over a 7.1 Mm path", *J. atmos. terrest phys*., **35** , 479-495,1973.
[6] D.D.Crombie, "Differences Between the East-West and the West-East Propagation of VLF signals over Long distances", *J. atmos. terrest phys*., **2**, 110-117, 1958.
[7] B.K.De and S.K.Sarkar, "Fluctuations in low frequency Signal strength Accompanying Seismic Waves". *Ann. Geophys*. **2**, 505-510, 1984.
[8] S. K. Sarkar and B. K. De, "Meteorological effect on long distant 40 kHz signal," *Arch. Met. Geoph. Biocl.,* **33A**, 365-379,1985.
[9] D.D.Crombie, "On the Use of VLF Measurements for Obtaining Information About the Lower Ionosphere, Especially During Solar Flares", *Proc. NATO Adv. Study Inst.* Norway, 118-133, 1965
[10] B.K.De and S.K.Sarkar, "Effects of solar 10.7 cm. radio flux and solar magnetic field on low frequency signal propagation", *Ind.J.Rad.Space Phys*., **23**, 213-216, 1994.