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Diurnal variation of 19.8 kHz signal propagation over long path to Suva

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1 INTRODUCTION

The navigational transmitters which operate in Very Low Frequency (VLF) band are used for long distance communication, positioning and timings. The VLF signals generated by navigational transmitters propagate in the guided mode between the Earth's surface and the lower region of the ionosphere which form the Earth-ionosphere waveguide (EIWG). At VLF, the Earth surface and the lower ionosphere act as good conductor. Therefore, the guided VLF propagation occurs with low attenuation and can be received literally around the world. Yokoyama and Tanimura (1993) first observed diurnal variation of amplitude of 17.7 and 22.9 kHz VLF signals propagated over long distances (> 5 Mm), with diurnal phase variations first reported by Pierce (1955) and Crombie *et al*. (1958). Their results showed that the phase advanced during sunrise, with pronounced steps coincident with amplitude minima. Some researchers have reported the diurnal variation of VLF transmitter signal amplitude/phase showing the sunrise and sunset effects (Crombie 1964; Ries 1967; Clilverd *et al*. 1999).

In this paper we present initial observations of 19.8 kHz signal from NWC (21.8°S, 114.1°E, 1MW) transmitter to Suva (18.1°S, 178.5°E), Fiji, during the period of September 2006- February 2007. We have used 1-min averaged amplitude and phase data recorded at 0.1 s resolution.

2 OBSERVATIONAL RESULTS

The signals at 19.8 kHz are received at Suva using the World-Wide Lightning Location (WWLLN) VLF setup Dowden *et al.* (2002) and is recorded using Software based Phase and Amplitude Logger termed as "SoftPAL". The SoftPAL VLF receiver can log amplitude and phase of seven transmitters at a time, with time resolutions ranging from 10 ms to 10 s. The signals are recorded at 10 Hz by SoftPAL and are run using Chart for Windows software. The transmitter receiver great circle path (TRGCP) distance for NWC-Suva path is 7.4 Mm. Typical diurnal variation of amplitude and phase of signal at 1 minute averaged values in decibels (over 1 μV) and degrees on 26 November 2006 is presented in Figure 1. In general, the average night signal (~ 50 dB) exceeds the average day signal (~ 43 dB) in strength giving a night to day signal ratio of 1.16. This is due to the higher attenuation of modes in the daytime than that in the nighttime. The signal emerging from the sunrise and sunset transition is associated with amplitude fadings (minima) and changes in the signal phase occurring around local sunrise or sunset. Around the time of sunrise and sunset along the transmission path three amplitude minima at sunrise labelled as SR_1, SR_2, and SR_3 and three amplitude minima at sunset, SS_1, SS_2, and SS_3 are observed. As seen from this Figure 1, the rapid change of phase takes place at the time of the amplitude minima. The rapid phase change is in the direction of decreasing phase delay during sunrise and in increasing phase delay during sunset.

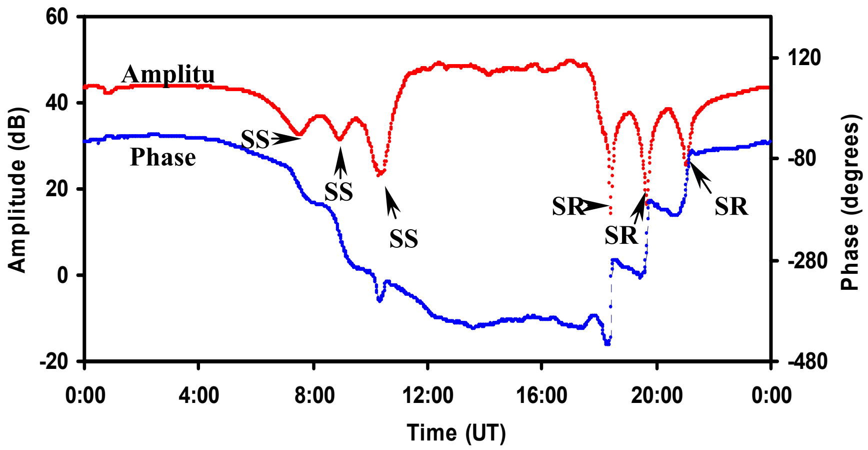

Figure 1. Typical variation of amplitude and phase of NWC signal at Suva on 26 November 2006.

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Data for November 2006 are overplotted in Figure 2 to indicate the reproducibility of the amplitude values over a 24 hour period. The respective phase values for this month are not plotted as the phase builds up over the day and deviates from reproducing its form over the days, however, the uniform and stepwise phase advances coincides very well with the amplitude variation over any day. The signal variability is more in night than in day indicating that propagation path is more stable in the day. Crombie (1964) suggested that at sunrise, for a west-to-east transmission, two waveguide modes are present in the dark part of the path between the transmitter and the dawn discontinuity and at the discontinuity the second mode is converted to first mode so that no second mode exists in the daylit part of the path.

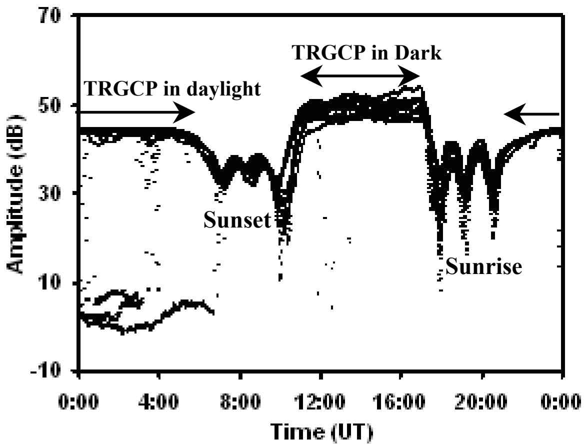

Figure 2. Diurnal variation of amplitude of NWC signal at Suva for November 2006.

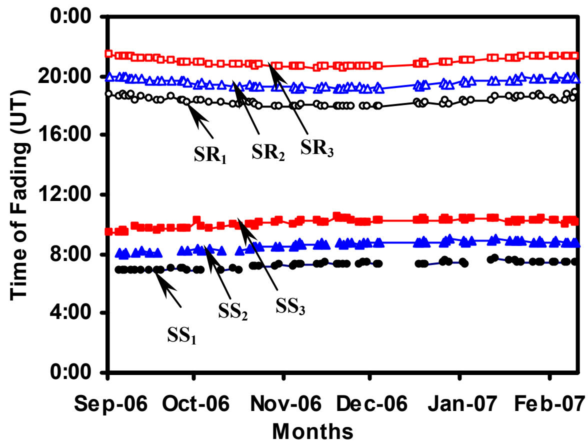

Figure 3. Variation in time of sunset and sunrise minima at Suva during September 2006 to February 2007.

Crombie showed that the consequences of these assumptions are that when destructive interference takes place between modes resulting minimum in VLF signal amplitude, the rapid phase change is also observed. In our case for NWC the rapid phase change was in the direction of decreasing phase delay during sunrise and of increasing phase delay during sunset which is in agreement with Crombie's theory. It is found that the number of signal minima at sunrise and sunset depend on the extent of the distance traversed by the signals in east-west direction under their TRGCP. Generally, if the signal traverses greater component in the east-west direction or vice versa, then more number of minima would be observed. It is interesting to note that the depth of fadings at sunrise is greater than at sunset. This is probably because the transmitter directly excites the interfering second order mode when it is in the nighttime portion of the path. However, at sunset the second order mode is created at the terminator. Thus, there is a likely difference between the sunrise and sunset mode conversion efficiencies. According to Crombie (1964), the depth of fading should increase as the sunrise terminator approaches the transmitter because the path under illumination is elongating hence increase in attenuation of the second order mode. Conversely, the depth of fadings should decrease as the sunset terminator moves to the transmitter because of decrease in the illuminated path length hence low attenuation of the second order mode. This is contrary to our results which show that the depth of fading of the NWC signal at sunrise decreases as the terminator moves from the receiver to the transmitter and increases at sunset. This disparity between the depth and pattern of minima indicates the more complex propagation conditions probably involving more than two modes at night and dominant day mode at the terminator converted into a series of night time modes on the paths like NWC-Suva during sunrise and sunset as has been also reported by Clilverd *et al.* (1999). Another interesting feature of the observation is the regularity (in time) with which the fadings occur. This is demonstrated in Figure 3 which is a plot of the times of signal minima on the NWC-Suva path for 12 days from every month during the period of September 2006- February 2006. It is clear that the times of sunrise fading repeat themselves with good regularity; however there is a slow monthly variation in the time at which the fades occur. Monthly variation in occurrence times of minima at sunset and sunrise as shown in Figure3 could be reasonably described by considering the monthly changes in the sunrise and sunset times at lower ionspheric altitudes (60-85 km) for fixed receiver locations (Ries 1967; Clilverd *et al.* 1999).

3 CONCLUSION

The significant findings based on results presented indicate that the signal strength is more in the nighttime than that in the daytime and diurnal variation shows three amplitude fading associated with phase decreases or advances both at the sunrise and at sunset. The deepest minima occur latest/later in time during the sunrise/sunset i.e. when dawn line in closer to receiver for sunrise and dusk line is closure to transmitter for sunset. The pattern of minima indicates the complex propagation conditions probably involving more than two modes at night and dominant day mode at the terminator converted into a series of nighttime modes.

4 ACKNOWLEDGEMENTS

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