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Response of the sub-ionospheric VLF/LF signals to the major SSW event of 2009

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Abstract

In this paper, sub-ionospheric Very Low Frequency/Low Frequency (VLF/LF) radio signals over the North Atlantic zone and North Pacific zone have been analysed during the major Sudden Stratospheric Warming (SSW) event of January, 2009. Signals from the transmitters like, NAA (24.0 kHz) and NKR (37.5 kHz) received at Germany and signals from the transmitters like, NLK (24.8 kHz) and NPM (21.4 kHz) received at Japan are considered for possible lower ionospheric response to the SSW event. Very clear and significant increase/decrease of average nighttime and daytime VLF/LF amplitudes from the quiet signals have been found associated with the SSW event.

1 Introduction

Fixed frequency Very Low Frequency (VLF) and Low Frequency (LF) signals having frequency between 3–300 kHz from man-made VLF/LF transmitters propagate in the earth-ionosphere waveguide. These signals generally reflect from the lower ionosphere region between 60–90 km and can propagate a very long distance with small attenuation rate. Recording of amplitude and phase of these signals from ground based receiver throughout day and night create a very good data set for research on the lower ionosphere region named as the D-region. Since the D-region is not accessible to balloons or satellites and is also difficult to get continuous echoes from this region using high frequency Radars, D-region properties can be better studied continuously by the VLF/LF waves [1, 2, 3].VLF/LF signals exhibit a regular diurnal (day/night) variation following sunrise/sunset, seasonal variation and also solar cycle variation [4, 5, 6]. Short term modification of VLF/LF signals include excess ionization during solar flares [1, 5, 7, 8, 9], Gamma ray bursts [10, 11, 12] and tropospheric lighting [13, 14] associated heating and electron precipitation processes. In addition, VLF/LF signals respond to various atmospheric forcing from below associated with atmospheric gravity waves, tides and planetary waves [15, 16, 17]. VLF phase retardation due to stratospheric warming are also observed in the past for some of the events [18, 19]. During sudden stratospheric events, northern hemispheric polar stratospheric temperatures tend to increase by at least 25 K in a week and the polar vortex tend to break out in two or three vortices. Large scale planetary waves originated from the polar vortex motion propagate from the polar region to equatorial region and at the same time couples the atmosphere and ionosphere via the upwardly propagating components [20, 21, 22, 23].This in turn modifies the ion-neutral balance in the ionosphere. The present paper tries to find this effect of the major SSW event of 2009 on the lower ionosphere via the disturbances observed in the sub-ionospheric VLF/LF signals.

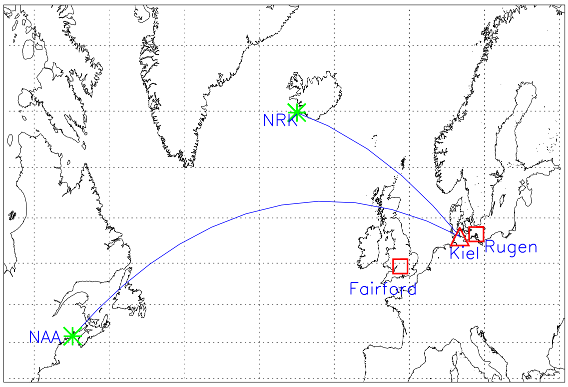

Figure 1. Great circle path between the transmitters (NAA and NRK) and receiver at Kiel, Germany.

2 Observed data

We use VLF/LF data received at Kiel, Germany from two transmitters (NAA (24.0 kHz) and NRK (37.5 kHz)) during January to March, 2009. Figure 1 shows the great circle paths between the transmitters and receiver. Figure 2 shows two years (2008-2009) of recording VLF amplitude data for the NRK and NAA signals respectively. Here signal amplitude in dB is plotted in color coded with time of the day in Y-axis and day of the year in X-axis. Black strips indicate absence of data. Seasonal variation of the ionospheric ionization can easily be noticed from the difference of signal strength in summer and winter. In winter time (from October to April) lower daytime (between 8–14 UT) amplitude

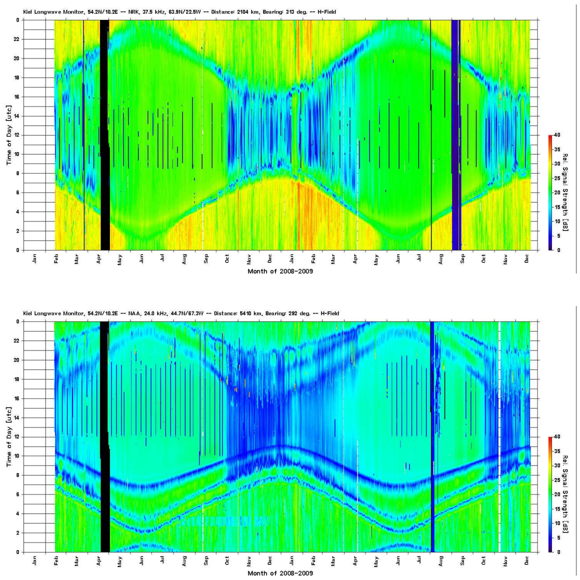

Figure 2. Diurnal variations of VLF amplitudes of the NRK (first panel) and NAA (second panel) transmitters received at Kiel, Germany.

indicates lower ionization than that of summer. Our interest is here the period of January 2009 to March 2009 when the major SSW event occurred. Stratospheric temperature data are taken from the NASA's Atmospheric Infra-red Sounder (AIRS) facility instrument (level 3 data) around the middle point of the propagation paths. The time period of the major SSW event of 2009, from January 10 to February 6, is characterized by the the quiet geomagnetic and minimum solar activities. The peak of the stratospheric temperature enhancement or peak of the SSW event occurred on January 23-24.

3 VLF/LF amplitude anomaly

Two hours amplitude average during nighttime and daytime have been taken from the VLF/LF diurnal curves to make time series of amplitude during the SSW period, January to March, 2009. In Figure 3, we plot the variation of stratospheric temperature variation at $\sim$31 km altitude around the mid-point (0.5° latitude $\times$ 0.5° longitude in resolution) of NRK-Kiel path (first panel) and average daytime (red) and nighttime (black) amplitude of the NRK signal (second panel). Variation of nighttime stratospheric temperature around the NAA-Kiel path (third panel) and nighttime signal amplitude for NAA (fourth panel) have been shown during the SSW period. We notice significant increase of daytime amplitude of NRK signal approximately by 10 dB from the quiet background amplitude level before and after the SSW event. In case of nighttime signal, we see first decrease of amplitude followed by an increase of amplitude by $\sim$10 dB for the NRK signal, while for the NAA signal we notice $\sim$6 dB increase due to the SSW event. Daytime signal amplitude for the NAA transmitter is not plotted here due to poor signal to noise ratio.

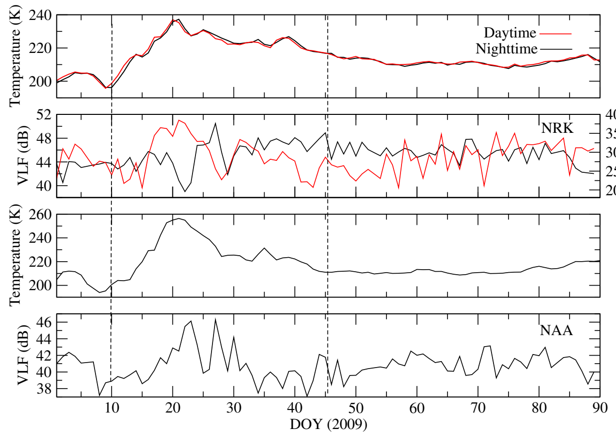

Figure 3. Variation of stratospheric temperature around the mid-point of NRK-Kiel path (first panel) during the SSW period. Variation of daytime and nighttime (second panel) average amplitude of the NRK signal received at Kiel. Nighttime stratospheric temperature variation around the mid-point of NAA-Kiel path (third panel) and corresponding nighttime VLF amplitude variation (fourth panel). Two dashed vertical lines indicate the duration of the SSW event.

Variation of VLF/LF amplitude mainly controlled by the lower ionospheric electron density and electron-neutral collision frequency profiles. From the VLF observation here, it is difficult to infer about the electron density distribution without proper simulation, because increase of VLF amplitude may indicate either increase or decrease in electron density in the lower ionosphere and vice versa. We look at the nearby ionospheric sounding data such as minimum frequency of E-trace (fminE) and critical frequency of F2-layer (foF2) from Fairford and Rugen station (also shown in Fig. 1). Average variation of fminE and foF2 between 9–12 UT are plotted in Fig. 4 for both the station. From the variation of fminE data, we can note that there is a oscillating tendency of E-layer electron density with 5-7 days periodicity. But from the foF2 variations we notice a slight decrease in foF2 frequency during the SSW period indicating decrease in electron density at that altitude.

We also analyse the NLK and NPM transmitter data received at Chofu (CHF) and Moshiri (MSR) in Japan. Great circle paths are shown in Figure 5. First panel of Figure 6 shows the variation of stratospheric temperature at nearly 31 km altitude around the mid-point of NLK-CHF path (black) and NPM-MSR path (red) from January 2009 to middle of March 2009. Average nighttime VLF amplitude for the NLK-CHF and NPM-MSR path are shown respectively in second and third panel. Dashed vertical lines indicate the occurrence time period of the SSW event. The lowest panel shows the variation of Dst index indicating very low geomagnetic activity. We note amplitude enhancement during this time for NLK signal. But for the NPM signal, we note both increase and decrease during the SSW period. Also, the amplitude responses of the NLK and NPM signals

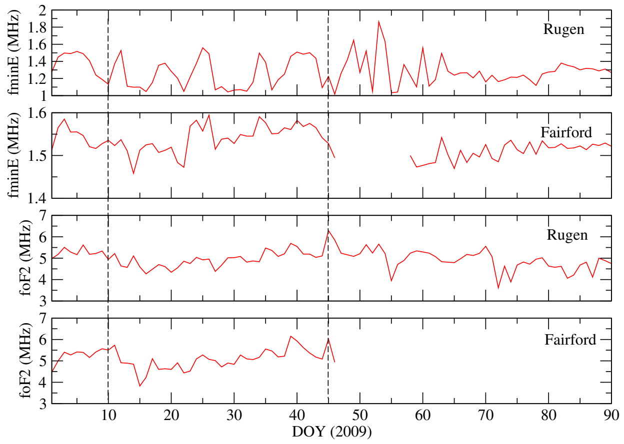

Figure 4. Variation of minimum frequency of E-trace (fminE) and critical frequency of F2-layer (foF2) in MHz during the SSW period from the sounding station at Rugen and Fairford.

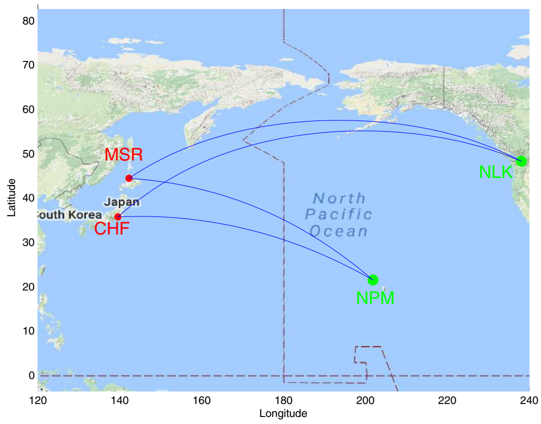

Figure 5. Great circle path between the transmitters (NPM and NLK) and receivers at Japan.

are lower than the NRK and NAA signals. This amplitude anomaly indicates changes in the of lower ionospheric conductivity profiles associated with the SSW event.

4 Conclusion

This paper reports the VLF/LF signals disturbances in detail due to the major SSW event of January, 2009. Depending on the propagation paths, significant increase/decrease or both increase and decrease of VLF/LF amplitudes during the peak of the SSW event are found which indicate disturbances in the lower ionospheric region. We believe that the upward propagation of tropospheric transient planetary waves resulting from the breaking of polar vortex during SSW period and their interaction with the tidal waves and small scale gravity waves are the main reason of ionospheric perturbation which affect the VLF/LF propagation

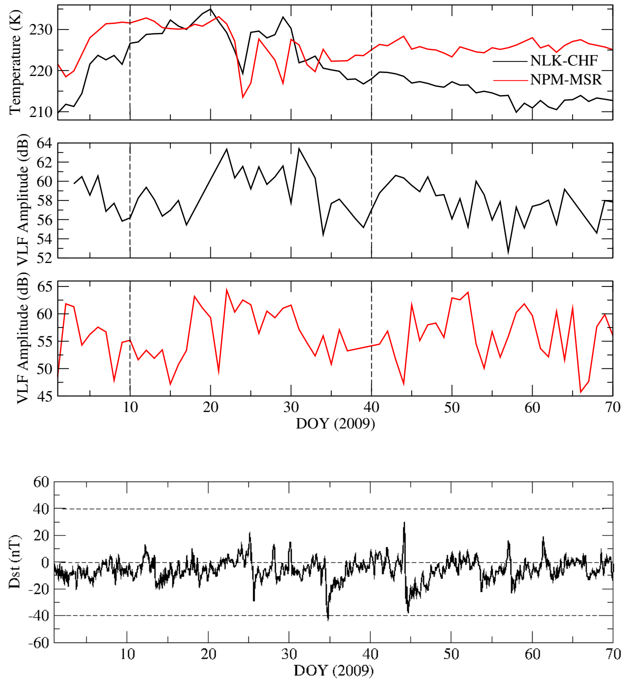

Figure 6. Stratospheric temperature variation approximately at 31 km (10 hPa) altitude around the midpoint of the NLK-CHF (black) and the NPM-MSR (red) propagation paths respectively (first panel). Nighttime average amplitudes of VLF signals for high latitude NLK-CHF path (second panel) and for the mid-latitude NPM-MSR path (third panel) from January to March 2009. Vertical dashed lines indicate the SSW time period. Variation of Dst index for the same time period (fourth panel).

in the earth-ionosphere waveguide. Theoretical simulation of VLF/LF amplitude profile during the SSW event is being done to quantify the exact changes in the electron density and electron- neutral collision frequency due to the above SSW event. Further investigations are necessary to identify all features of VLF/LF anomalies during SSW events.

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