A Study On The Final Phase Of The Bardarbunga Volcano Of 2015 Using Vlf Wave Of Nrk Signal Of Iceland Received At Kiel Longwave Monitor

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Abstract: Seismo-ionospheric changes often affect the VLF waves resulting in possible changes in the terminator times and often lead to night time fluctuations. The Bardarbunga volcano which started on 2014 ended on the last days of February of 2015. In this paper we present the results of the VLF analysis of the first three months of 2015 using a signal of 37.50 KHz where an analysis on the sunset terminator time, D-layer dissipation time, daytime fluctuation and night time fluctuation of the VLF amplitude was done. We contrasted the values of these parameters for the first two months of 2015 where the volcano was active with third month of 2015 when the volcano had completely subsided. The Sunset terminator time and the daytime fluctuations in the VLF amplitude for the first two months showed no major anomalies. The anomaly in the D-layer disappearance time and night time fluctuation count reached its peak values for the volcanically active months.

Index Terms: VLF/LF, D-layer, volcanic activity, sunrise terminator time, D-layer dissipation time, night time fluctuation of VLF amplitude, day time fluctuation of VLF amplitude

1 INTRODUCTION

Study on the D-layer of the atmosphere of Grindavik, Iceland using the sunrise terminator time and D-layer formation time, both of which hinted towards a possible anomaly resulting from the volcanic as well as tectonic activities was published in the September 2016 edition of IJSTR[1]. We present an extension of the paper with an analysis on the sunset terminator time, D-layer disappearance time, daytime fluctuation of the VLF amplitude and night time fluctuation of the VLF amplitude. The central difference between the paper by published on the study on the D-layer of the atmosphere of Grindavik, Iceland in IJSTR September edition of 2016 [1] is that in the former paper the authors looked at the Sunrise Terminator time and D-layer formation time. In this paper we try to look if the ionospheric perturbations due to the volcano of Bardarbunga can be picked in the sunset terminator time, D-layer dissipation time and night time fluctuations of the VLF amplitude. Several studies have shown that anomalous behavior of D-layer disappearance times and sunset terminator times have also been studied as VLF precursors to seismic events [2], [3], [4], [5], [6], [7], [8].. Night time fluctuations have also been found to be associated with seismic activities [9], [10]. [11]. [12]. [13]. [14]. We analyzed such parameters and checked if anomalies associated with such parameters could be seen with the Bardarbunga volcano. Since the volcano and the seismic activity associated with the volcano was active for January and February of 2015 but not on March 2015, we analyzed sunset terminator time, D-layer dissipation time, daytime and night time fluctuations for the respective months.

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2 The Transmitters and the Receivers

The NRK signal was transmitted from Grindavik, Iceland and is received at the Kiel Lonwave Monitor located at Germany. Kiel Longwave Monitor is located at the co-ordinate of 54.2 degree north and 10.1 degrees to the east. The NRK signal of 37.5 kHz is located at the co-ordinate of 63.9 degree north and 22.5 degrees west [15]. The transmitting system and the receiving systems are located at a distance of 2106 km which is exclusively ocean dominated. A bearing: 313 degree of H-Field is associated with the receiver. Kiel Longwave Monitor has two formats in which the data is collected- as a one spectrum per second as well as a one spectrum per second. For the purposes of this work, we are analyzing the data that is available in the form of one spectrum per minute.

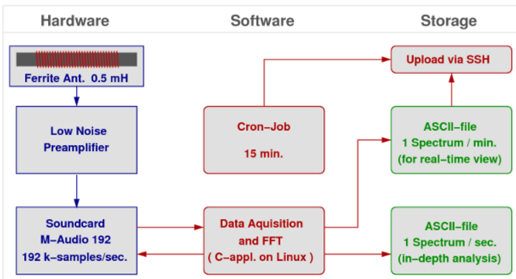

***Fig 1:** Block diagram of Kiel Longwave Monitor [1].*

3 Methodology of Analysis

3.1 Terminator time method

The sunset terminator time was noted as the time where a dip in the daytime amplitude of the VLF wave was observed after the geographical sunset has taken place [2] as shown in figure 2. The geographical sunset time and the sunset terminator time possess a theoretical disagreement of 45 minutes to one hour. A larger deviation in the difference of these parameters might also point at a possible precursor to the ionospheric changes related to terrestrial events [2, 3, 4, 5].

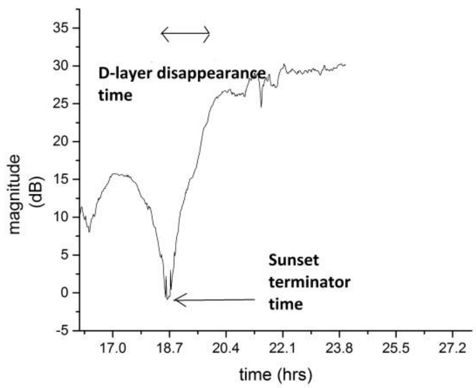

***Fig 2:** a figure of the intensity profile of 6th March 2015 which is zoomed in t show the sunset terminator time and D-layer disappearance time*

The D-layer disappearance time was noted as the time taken by the VLF signal from a point of sunset terminator time to the time when the VLF signal reached to a stable value [2]. This value was recorded in the unit of minutes. The data points for which the values of the D-layer disappearance time as well as the sunset terminator time exceeded the ±2σ were considered to be anomalies.

3.2 Daytime/Night time fluctuation of the VLF amplitude

There have been quite a few methods of analysis of the night time fluctuations of VLF amplitude applied for the study of short term earthquake prediction [11], [12], [13], [14], [19], [20]. We apply similar method for the study of Bardarbunga volcano. The night time fluctuation of the VLF amplitude was studied in the same way where that was studied by S.Ray et al 2004. The night time amplitude was obtained by expurgating the data of one day after sunset terminator time and the next day up to the sunrise terminator time. The data thus expurgated from two different days when cuddled together to obtain the value of night time amplitude. This process is figuratively shown in figure and figure. The two highlighted portion of the figures 3 and 4 are mixed to obtain the night time value of VLF amplitude.

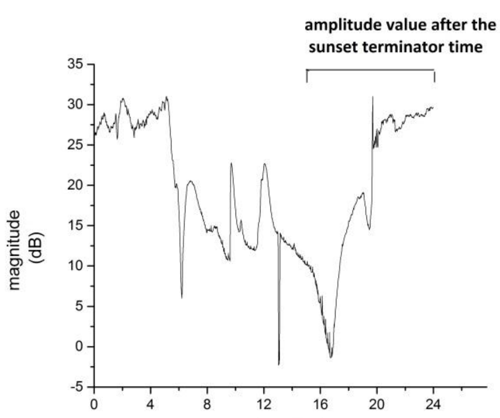

***Fig 3:** Intensity profile of 15th May 2015 where the amplitude value of the VLF wave is shown*

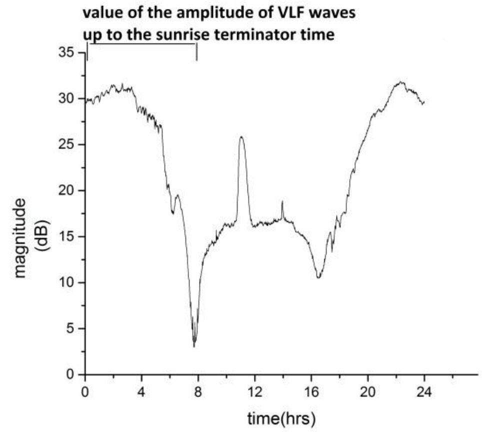

***Fig 4:** Intensity profile of 16th May 2015 where the amplitude value of VLF wave is shown*

The data was further thrown away from the right of the sunset terminator time of a day and the left of the sunset terminator time of the next day]. The cutting off of the data from one day to the next was dependent upon months to exclude the effect of the terminator time in the data [14]. For taking the daytime time values of the amplitude of the VLF data, we took the portion of the data between the terminator times of a day of a particular day. An example is shown in figure 5.

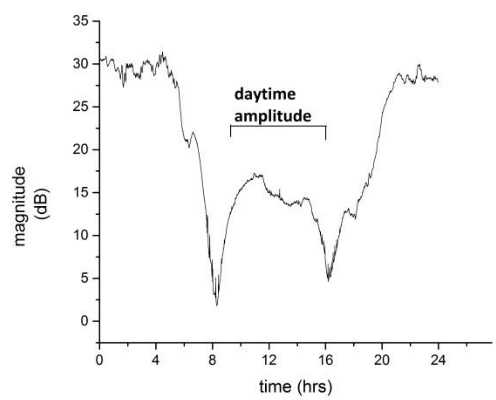

***Fig 5:** a figurative demonstration of the daytime amplitude of the VLF data. The figure corresponds to the VLF signal of NRK for 13th March.*

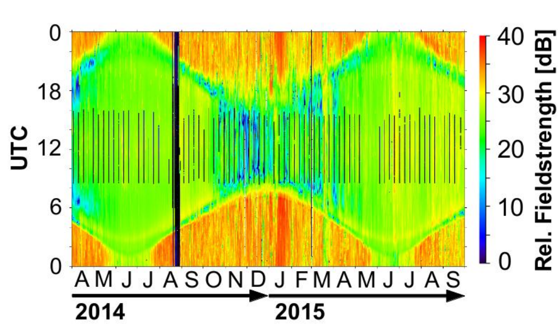

***Fig 6:** cylindrical projection of the NRK signal from 2014 to 2015[1].*

4 RESULTS and DISCUSSIONS

4.1 Sunset Terminator times

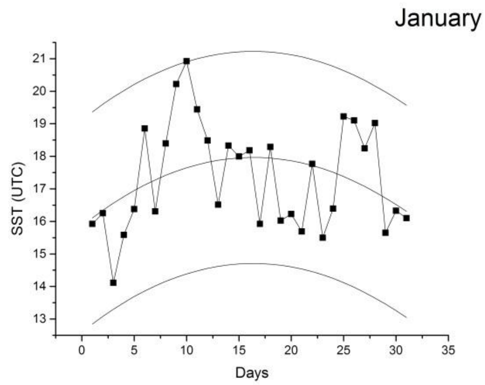

Fig: 7 *Variation of the Sunset Terminator time (SST) for the month of January.*

Nothing alarming was noticed in the sunset terminator times for the months of January and February as shown by figure 7 and figure 8. Although at some days, the terminator times were perilously close to the +2σ line (the curved lined shrouding the data points of sunset terminator times), they did not exceed the +2σ line and therefore could not be considered as an anomaly.

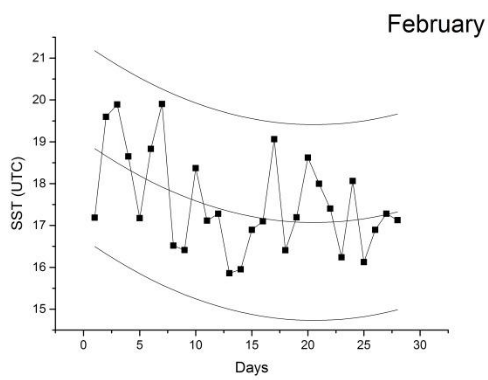

Fig: 8 *Variation of the Sunset Terminator time (SST) for the month of February*

However, in the month of March, specifically 22nd March, the Sunset terminator time crossed the +2σ line as shown in figure 9. Since, no seismic events were recorded in Bardarbunga during this time or in the subsequent months; this cannot be regarded as precursor to a tectonic activity. Other ionospheric events such as CG flashes might have caused the unusual deviation of the sunset terminator time.

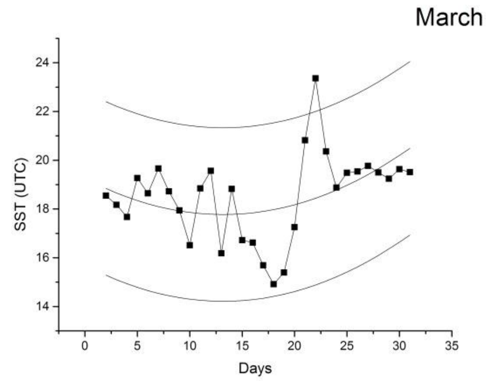

Fig: 9 *Variation of the Sunset Terminator time (SST) for the month of March*

4.2 D-layer disappearance time

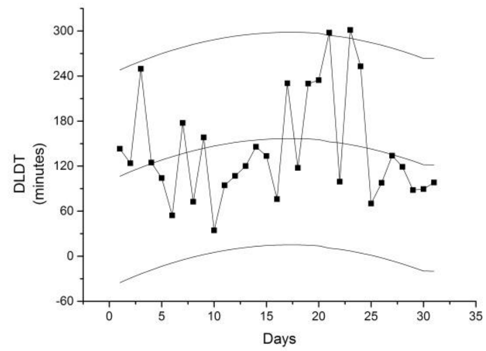

Fig 10: *D-layer disappearance time for the month of January*

Similarly, no unusual activity regarding the volcanic activity can be derived from the D-layer disappearance time (DLDT) of January, February and March as shown by figure 10, figure 11 and figure 12. The times were well within the standard ±2σ lines, which are indicated as the curved lines which have acted out as boundaries within which almost all of the data points have been found. The days where the data points have crossed these lines such as that in January 21, January 23 and March 13 have not surpassed them clearly enough to be regarded as anomalies.

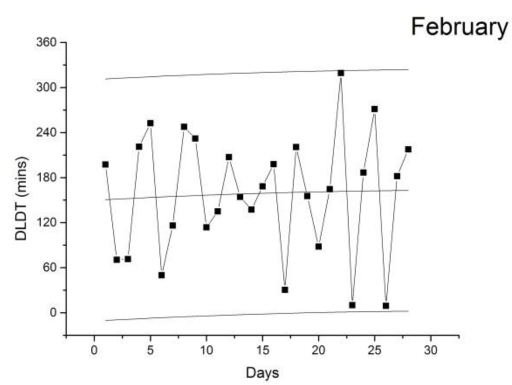

Fig 11: *D-layer disappearance time for the month of February*

A peculiar feature of the D-layer disappearance times for the first two months the frequency of the data points that lie in close proximity of the ±2σ lines is 3 per month . This number is reduced to 1 for the month of March. This might be due to the fact that a lot of gases ejected from the Bardarbunga volcano during its active phases (January and February) were altering its surrounding atmosphere [16], [17]. However, from the month of March no ejection from the volcano was seen and therefore the number of anomalous data points might have dropped [18].

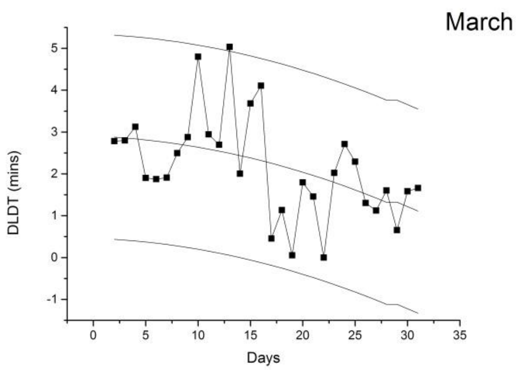

Fig 12: *D-layer disappearance time for the month of March*

4.3 Daytime fluctuation in the VLF amplitude

The daytime fluctuation counts did not reveal anomalies. Since, the daytime fluctuations are dominated by the Sun and rays emitted from it, anomalies associated with seismic and volcanic activities are well captured only in the night time fluctuations of the VLF amplitude. The counts essentially remained constant for the three months. The daytime fluctuation count remained between the values ranging from 400 to 500 throughout the months as revealed by figure 13, 14 and 15.

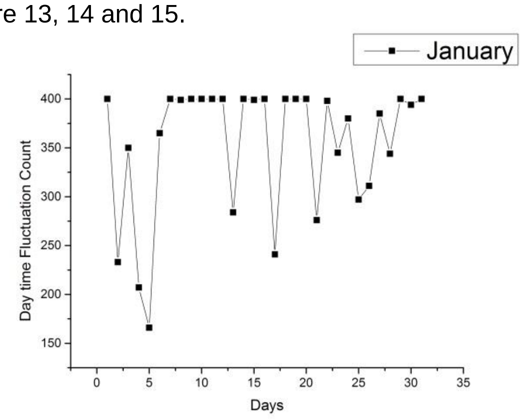

Fig 13: *daytime fluctuation for the month of January*

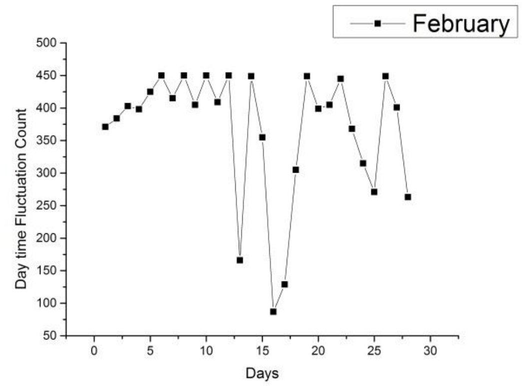

Fig 14: *daytime fluctuation for the month of February*

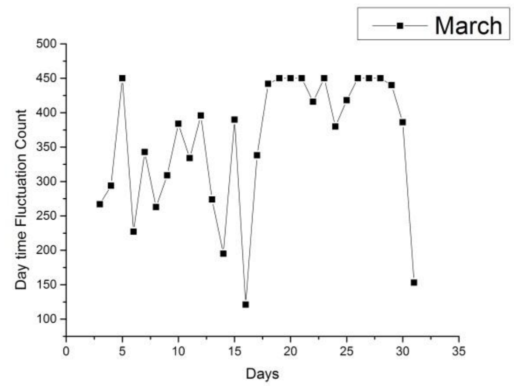

Fig 15: *daytime fluctuation for the month of March*

4.4 Night time fluctuation in the VLF amplitude

The night time fluctuations in the VLF amplitude revealed that number of counts spanned exactly in the way the D-layer dissipation times did for these months.

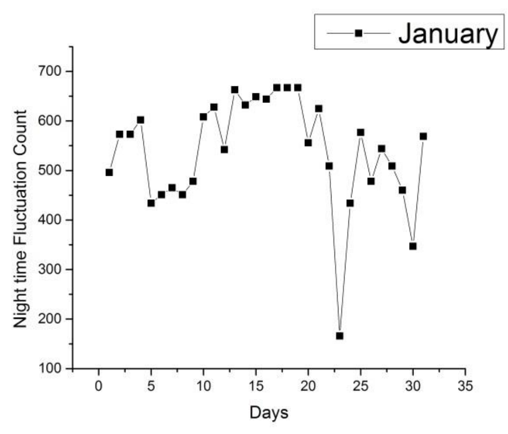

Fig 16: *night time fluctuations count for the month of January*

As shown in figure 16 and figure 17, the average number of night time fluctuation counts for the months of January and February were in the excess of 600 counts per day whereas in the month of March this number comes down to a paltry figure of mere 423 counts. This might be attributed to the volcanic activity active only in the months of January and February as seismic activities have been reported to influence anomalous behavior in the night time fluctuation

[14]. As hundreds of seismic activities were recorded in the month of January, a few noticeable events in the month of February and none in March [16], [17], [18], the high number of night time fluctuations might be correlated to the seismic activities of Bardurbunga.

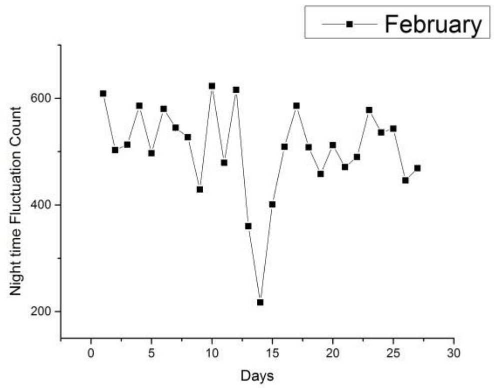

Fig 17: *night time fluctuations count for the month of January*

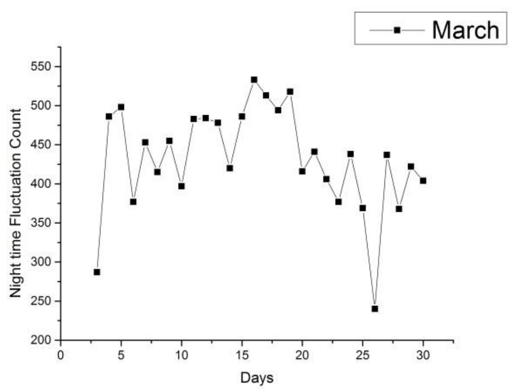

Fig 17: *night time fluctuations count for the month of January*

5. CONCLUSIONS

We found no difference in the sunset terminator time and the daytime fluctuation of the VLF amplitude before and after the volcano. However, the D-layer dissipation times and night time fluctuation values revealed to us that these values tended to be at their maximum during the months where the volcano was active and tapered off on the month it was quiescent.

6. REFERENCES

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