Investigation of anomalous perturbations in VLF signals and correlation with seismic activity

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Abstract

Prior to earthquakes anomalous perturbations in the ionosphere have either been observed as fluctuations in the F-region critical frequency, foF2, or as deviations in VLF signals. Such phenomena have been recorded up to 6 days before the main shock, making their identification imperative in aiding in earthquake prediction. However, a lack of reproducibility of the events and the large scale effect of solar activity on the ionosphere, isolation of seismogenic signals is difficult. Using narrowband receiver data from Hungary, VLF waves are analyzed to investigate the presence of anomalous perturbations, which are then correlated with seismic activity.

Introduction

Investigations of ionospheric signatures possibly related to seismic activity have been carried out as case studies of individual strong earthquakes [1, 2, 3], or as comprehensive studies over a few years in a certain region [4, 5, 6]. One of the two most credible types of anomalous observations is the dramatic decrease in the F-region critical frequency, foF2, by up to 50% [3]. The other is deviations in VLF signals from quiet-day curves [7].

Anomalous variations in foF2 had to first be defined, given as when the value of foF2 observed on a particular day either exceeds the lower or upper bounds of the previous 15-day running interquartile ranges [1]. The 15-day window was chosen because at the time that was the period of time between earthquake recurrence, hence a good reflection of unperturbed days.

Investigations of the foF2 fluctuations showed that the strength of the lower bound deviations are far greater than those of the upper, thus only lower bound excursions were considered as good indicators for anomalous signals. The magnitude of an earthquake proves to be a vital parameter in anomaly analysis. A study of Taiwan earthquakes between 1994-1999 revealed that earthquakes of magnitude 5 and greater had a 73.8% chance of having associated precursory anomalies being observed, and shocks of M>6 possessed a 85% probability [1]. Another study showed similar results of M>5 and M>6 shocks having probabilities of 73% and 100% of being preceded by anomalous drops in foF2 in the week leading up to the earthquake [8]. Not only was it concluded that the magnitude determined whether there would be anomalies present, but also the number and strength of the anomalies. Looking at the 1999 ChiChi earthquake, M>7.3, that particular event was preceded by 3 anomalies 1, 3 and 4 days prior to the main shock, however, the other shocks studied ranged between 6<M<6.5 and only had 1 associated anomaly. The strength of the ChiChi anomalies were much greater than any observed for the other earthquakes.

One of the most characteristic and distinguishing traits of seismogenic ionospheric disturbances is that the signals are regional and are not observed at great ionospheric distances away from directly above the site of the future epicenter. The chance of observing ionospheric signatures related to earthquakes is only appreciable within a radius of 150km from the epicenter [5].

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The other type of anomalous ionospheric signature possibly related to seismic activity are deviations of VLF signals from their quiet-day curves. The quiet-day curves are constructed of different years data around the same days in question but during periods of low activity in general. Activity here means any combination of geological or solar phenomena that could effect the signal and bias the observations.

The VLF waves propagate between transmitters and receivers on the ground, reflecting off the atmosphere-ionosphere boundary. There is very little attenuation while the waves pass through the Earth-Ionosphere waveguide(EIWG), hence any appreciable anomalous fluctuation recorded in the signal at the receiver will be due to the state of the lower ionosphere that the wave reflect off it. Wave-like oscillations with periods of 3 hours were observed in VLF signals along the propagation path between Japan and Western Australia [7]. Such perturbations lead earthquakes in the area by 1-3 days. Comparing regional seismicity and anomaly presence produced a correlation coefficient of 0.5. The maximum correlation occurred 1-2 days prior to the onset of an earthquake. The positive sign of the correlation, taking into consideration the irregular and unpredictable behaviour of seismic events, shows a promising relation between observed ionospheric perturbations and seismicity.

For an ionospheric anomaly to be driven by a seismic event the earthquake magnitude must meet a threshold value of M>5.5, however, only M>6 shocks stand a significant chance of being preceded by detectable precursors [9]. The perturbed region of the ionosphere is tightly bound to the effected area on the ground. The Dobrovolsky formula, which is widely used to calculate such an area as it relates the radius of the effected area, R, on the ground to the magnitude, M, of an earthquake, is given by $R=10^{.043M}$. A study of the 2004, M=9, Sumatra earthquake on the 26th December showed extended periods of VLF signal fluctuation commencing a few days before the main shock and continuing on until the beginning of the next month. The same period was accompanied by periods of quiet geomagnetic and seismic activity before the earthquake occurred [10].

Bay-formed disturbances were reported in another VLF signal analysis [6]. Such protrusions in the signal occur when the signal has a strong increase(or decrease) followed by a period of relative constant value and ends with another sharp decrease(or increase) back to the quiescence levels. The number of such perturbations that lasted for 2-3 hours was reported to increase in the 6 nights approaching an earthquake. The 3 closest nights to the shock had more disturbances by a factor of 1.5-2 over the farthest 3 nights.

Current Work

My work concentrates on earthquakes occurring between 01/07/2007 – 31/01/2008. The earthquake data were collected from the USGS website. Figure 1 depicts the distribution of the earthquakes globally for this period, as well as the transmitter, receiver locations and the propagation paths that the VLF signals followed. Using the Dobrovolsky formula to calculate the preparation zones of the earthquakes, earthquakes that would have a significant chance of affecting readings along a particular transmission path were identified. Due to the strictly regional area of the ionosphere that is affected by an impending earthquake, only the area of the ionosphere above the preparation zone would have a significant chance of being perturbed. Using data from narrowband receivers situated in Hungary, the VLF waves are analyzed. A wide range of VLF frequencies are used from 19.6kHz to 45.9kHz. First the quiet-day curves are to be constructed. To accomplish this times of quiet seismic activity around the dates in question are used, by averaging the 7 days leading up to the earthquake. Then the times of the earthquake occurrences are compared to the quiet-day curves and any significant deviation will be considered as anomalous. Figure 2 shows the quiet-day curve(black) and a single day, 06/09/2007, prior to the magnitude 8.5 earthquake indicated by the yellow star, that occurred on 12/09/2007 along the 19.8kHz transmission path between Hungary and North West Australia. There is clearly an anomalous drop in the signal with regard to the quiet-day curve, possibly due to the impending large earthquake.

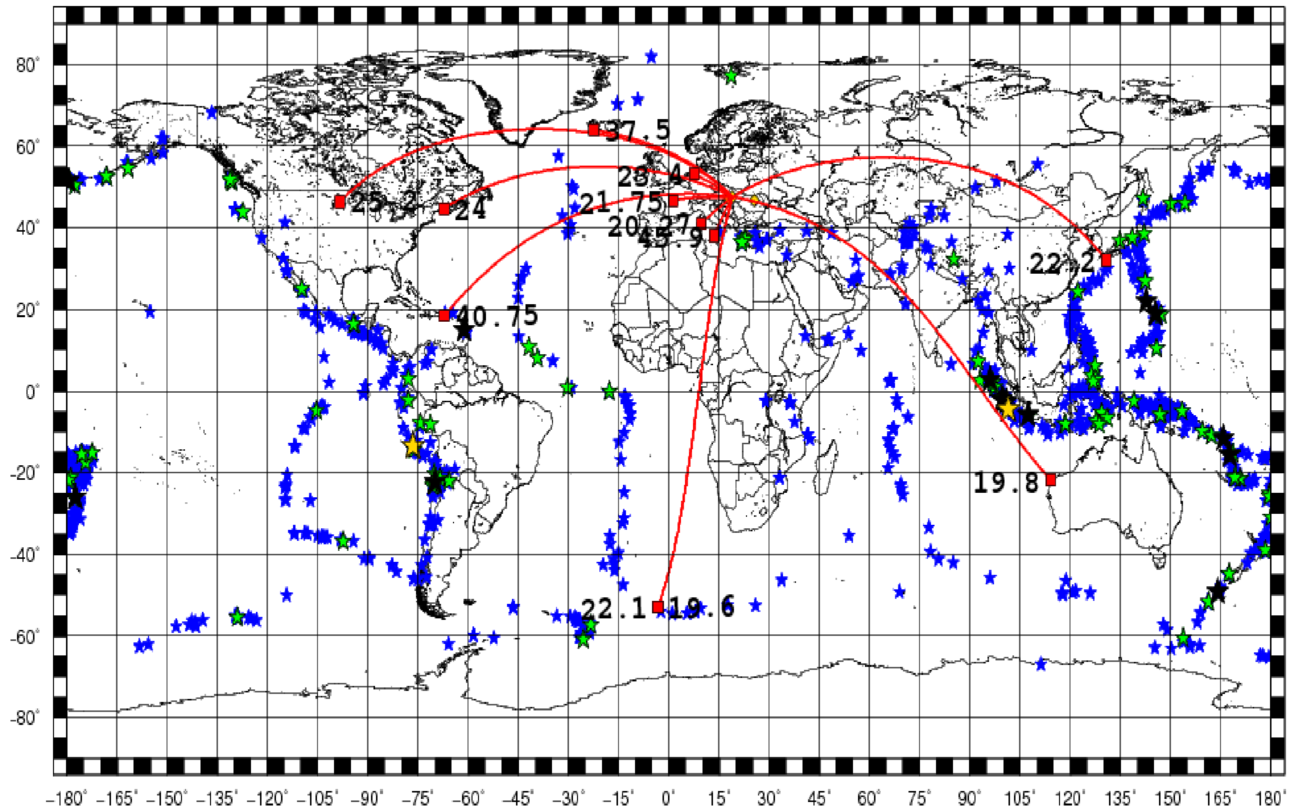
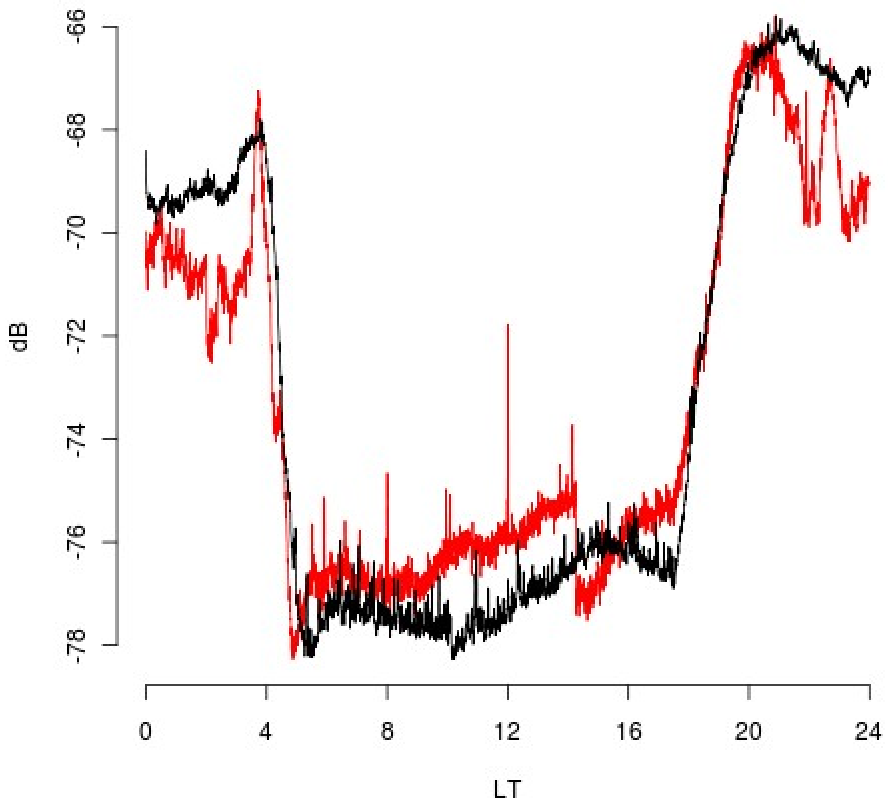


Figure 1: Earthquake distribution for the study period 01/07/2007-31/01/2008. Legend: blue stars 5<M<5.9; green stars 6<M<6.9; black 7<M<7.9; yellow stars 8<M<9. Yellow diamonds – receivers. Red squares-transmitter stations with transmission frequency. Red lines- great circle paths



*F*igure 2: Quiet-day curve (black) superimposed on single day data (red)

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