# Seismic effect on the propagation of subionospheric LF radio waves in Italy

Y. Fukumoto[1] , M. Hayakawa[1] , and P. Biagi[2]

(1) Department of Electronic Engineering, The University of Electro-Communications,

(2)Department of Physics, University of Bari, Bari, Italy

(1)1-5-1, Chofugaoka, Chofu-si, Tokyo, 182-8585,Jpan

(2) Via Orabona, 4-70100 Bari, Italy

fukumoto@whistler.ee.uec.ac.jp

Abstract

The data of subionospheric LF signal  intensity observed in Italy during the period from March 15, 1997 to December 31, 1998, have been used to study the seismo-ionospheric effects taking place in and around Italy. Two different methods of analysis are utilized(terminater time analysis and fluctuation method). The signal amplitudes at the sunrise time are found to increase before the quakes taking place close to the observing stations, which is apparently as an effect of shift in terminator times. A significant effect is also detected for the signal characteristics for the LF signal passing through the region of earthquakes in the middle of the great circle path. However, no significant effect was observed for the 3rd event.

## 1. Introduction

Ionospheric perturbations associated with earthquakes have been recently extensively studied by means of anomalies of subionospheric propagation signals transmitted  from the existing VLF/LF transmitters [ Hayakawa et al.,1996; Molchanov and Hayakawa,1998 ; Biagi,1999], which seems to be very promising for the short-term earthquake prediction. Especially, Hayakawa et al.(1996) and Molchanov and Hayakawa(1998) have originally proposed the use of terminator times in the diurnal patterns of amplitude and phase in finding out the sismo-ionospheric effects, and have found that the terminator time is extremely useful for the study of VLF/LF propagation anomaly(that is, seismo-ionospheric perturbations). Our previous studies have yielded that the ionosphere seems to be lowered by a few kilometers before the quake, and also the atmospheric oscillations with period of    5 days or    10 days would play an important role in the ionospheric effect(Molchanov and Hayakawa, 1998).

In this paper we study the propagation anomalies in subionospheric propagation of LF broadcasting transmitter signals in association with the earthquakes in and around Italy, and we will study the association of LF propagation anomalies with earthquakes by means of two different analysis methods(terminator time method and fluctuation method).

## 2. Data source and analysis method

The data on subionospheric LF signals are available during the period of 1 year and nine months from March 15, 1997 to December 31, 1998. Three LF transmitters are used; (   )189kHz(Caltanissetta), (   )216kHz(Monte Carlo), and (   )270kHz(Ceskoslovensko). The location of these transmitters are illustrated in Fig.1, and those LF subionospheric signals are observed at two observing stations (Assergi and Peschiera) as in Fig.1. The approximate distance from the observation stations is about 550km for 189kHz transmitter, about 550km for 216kHz and 800km for 270kHz. The signal intensity is measured every 10 minutes.

During the whole period, there were observed 340 earthquakes (with magnitude greater than 1.8), whose depths are almost less than 10km (except a few). Also many earthquakes took place nearly at the same place in the central Italy as shown in Fig.1, which are close to the observation stations. One region we pay attention is the central Italy, in which the quake (with M=6.4) happened on September 26, 1997, followed by after-shocks till December 8,1997. At the same place we had rather large quakes on March 26, 1998 (M=5.6) and on August 15, 1998 (M=4.8). Not only the central Italy, but also the north-east region of Italy, was rich in seismic activity; that is , the quake on March 13, 1998 (Ms=5.2), April12, 1998 (Ms=6.0), May 6, 1998 (Ms=5.1) and August 31, 1998 (Ms=4.9), which are located nearly in the middle of the great circle path(270kHz-observation stations).

Two different methods of analysis have been utilized in this paper; (a) terminator time method and (b) fluctuation method. Of course, these two methods are closely correlated with each other. The first method has already been found to be very effective for identifying the seismo-ionospheric perturbation [ Hayakawa et al.,1996; Molchanov and Hayakawa,1998]. The diurnal variation of signal amplitude shows an increase during night and a depletion at day and there are the time of clear transition between day and night, and these transition times with a minimum being called Tm(morning terminator time) and Te(evening terminator time). By reading these times(Tm and Te), we estimate the variation of those times by means of the concept of 2  (  : standard variation)

The second method is called "fluctuation method". It is useless to study the amplitude fluctuation at each   .T, because sunrise and sunset times exhibit a clear seasonal variation. So that, we first estimate theoretically the seasonal variation of sunrise and sunset at the two observing station, and we get the signal amplitude at such sunrise and sunset times (and also ± 0.5hr, ± 1.0hr, ± 1.5hr, and ± 2.0hr). In this sense this fluctuation method is also related with the terminator time method.
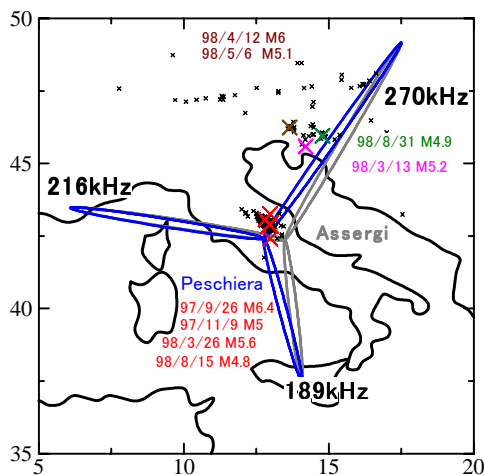


Fig.1   LF transmitters and
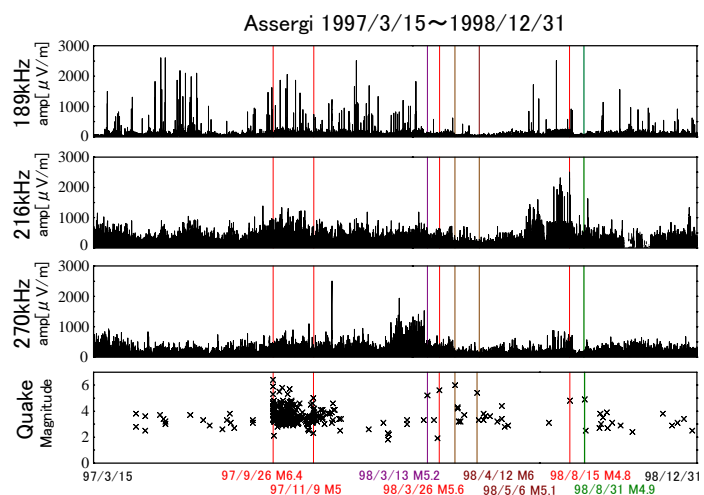           observing stations



Fig.2   Observed data at Assergi

3. Analysis results

Fig.2 shows the summary plot of the signal intensities for those three transmitters observed at Assergi during the whole observation period. The variation of the LF signal of 189kHz does not

exhibit so obvious diurnal pattern, and also it includes many inpulsive signal(the reason is not clear). So that, we do not pay attention to this frequency. From this figure we can notice the two points; (  ) a significant increase in signal amplitude(216kHz) before an earthquake in August, 1998 and (  ) a significant increase in amplitude(270kHz) before the quakes in March, 1998.

The result of terminator time analysis is summarized in Fig.3(a), in which the long term variation for terminator time(216kHz, at Assergi) is plotted for sunset and sunrise, together with the estimated variation of the times of Assergi ground sunrise and sunset , as already been found in Hayakawa et al. (1996). In order to avoid the seasonal variation and to make the statistics more reliably, we have used the difference between the measured Tm and Te and the ground sunrise and sunset times, and Fig.3(b) is the result plot only for Te. Taking into account the rough time sampling (10 minutes), the terminator time method in this paper is not so convincing as in Hayakawa et al. (1996) and Molchanov and Hayakawa(1998).
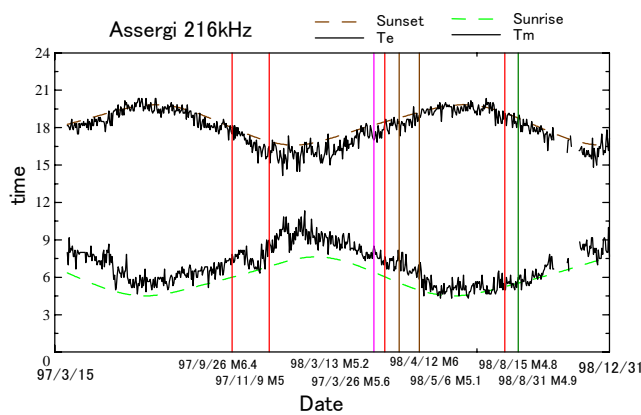


Fig.3(a)   Tm, Te and Sunrise, Sunset Time
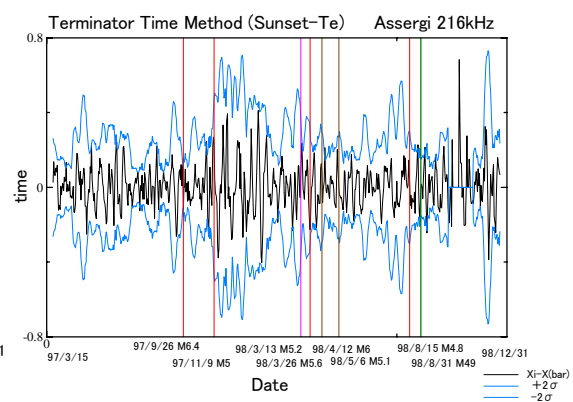          (216kHz, Assergi)

Fig.3(b)   Terminator Time Method
          (216kHz, Assergi)

So, with taking into account the concept of terminator time, we have re-plotted the amplitude at the sunrise(± 0.0hr) at Assergi in Fig.4, by calculating the sunrise time at Assergi and taking the amplitude at the moment(every 10minutes) closest to the sunrise time. Similar plots are made for other times around sunrise(± 0.5hr, ± 1.0hr, ± 1.5hr, and ± 2.0hr) and the same for sunset. Fig.4 includes a lot of useful and convincing information. As you see during the whole period, the first period is September-November, 1997, the second, March-May 1998, and the 3rd, August 1998. The upper two panels are for the signal amplitudes(216kHz and 270kHz) at Assergi at sunrise(± 0h), while the 3rd and 4th panels indicate the fluctuation result (black curve (average over ± 1days), and blue lines, 2   (  :standard deviation,± 7days)). Significant findings can be summarized as follows; (a) A noticeable increase in signal amplitudes at 216 and 270 kHz before the quake on September 26, 1997, followed by a subsequence enhancement. In close association with these behaviors, we could find out a significant increase in the amplitude fluctuation(look at ± 2    line) just around the September quake. (b) A significant increase is observed at 270kHz, and a corresponding large fluctuation in amplitude(2    line) is also found before the quakes in March, 1998. These abnormal behaviors are obviously associated with the quake on March 13, 1998 taking place on the great-circle path from Assergi to the 270kHz transmitter, because no any remarkable anomalies are seen on 216kHz path. (c) No remarkable effect is found for the quakes in August,1998. (d) Similar tendencies can be seen for other times like ± 0.5   ± 2.0hr, but those for the sunrise(± 0.0hr) are most recognizable.

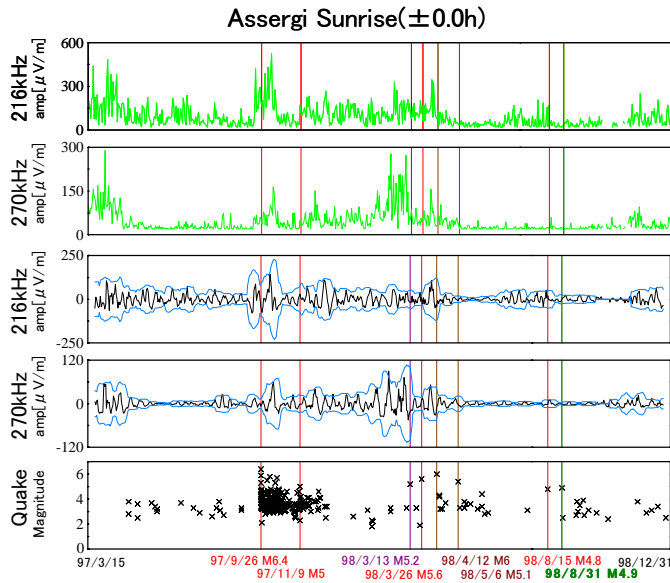Fig.4    The result with the fluctuation
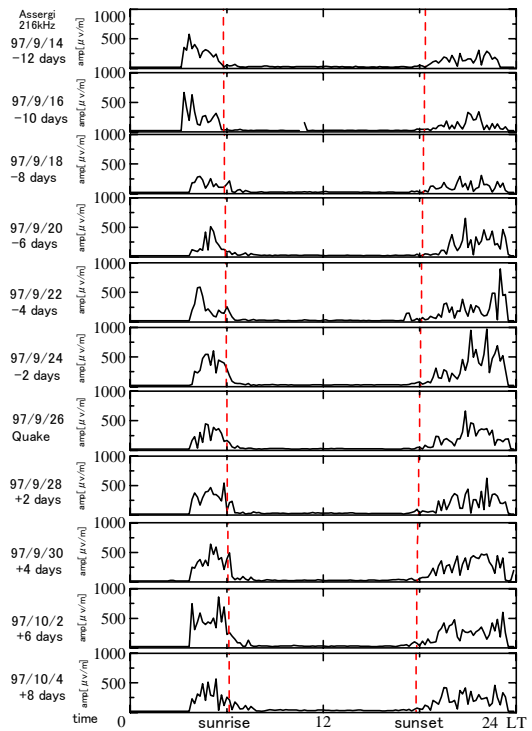          method at Assergi sunrise
          (216kHz and 270kHz)



Fig.5    A sequential plot   of diurnal
          variation of signal amplitude
          (216kHz, Assergi)

## 4. Conclusion and discussion

Looking at Fig.3(a), the significant shift in   terminator times is of the order of 30minites to 1hr, and the characteristics in this paper for the terminator times for the events studied is that the Tm shifts to later hours, and the Te shifts to early hours in these cases (in a complete contrast to that for a short-distance propagation for the Kobe earthquake(Hayakawa et al., 1996)), when we have shifts in terminator times. As is shown in Fig.4, we notice an increase in signal intensity and the increase in signal fluctuation are found to start about 10 days to one month before the quake. This is seen apparently as a signal increase, but it is probably due to the shift in terminator times as mentioned above. This is confirmed in Fig.5, which is just the result for the quake on September 26, 1997. This indicates that until 12-10 days before the quake the signal intensity at sunrise is relatively weak, but it is found that the signal at the sunrise exhibits an increase, and this increase still continues even after the quake. While, the behavior in Fig.5 for the moment of sunset is not so obvious as compared with that for sunrise. As the future work, we need the theoretical propagation characteristics (shift in terminator times) by modeling the seismo-ionospheric disturbances

References
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