Electromagnetics in Earthquake Prediction

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Summary

Despite the general pessimistic views on earthquake prediction, in particular on short-term prediction, researches based on electromagnetic methods have recently been extremely active. In some cases, actual short-term prediction has been in practice. However, their recognition in wider scientific community is unduly lagging far behind the real progress of investigation. Important characteristics of probable electromagnetic precursors are their appearances in a wide frequency band, covering from DC to VHF ranges, possibly involving many different processes. Reported precursory phenomena can be classified into two categories: one is the pre-seismic emission of signals from focal zone and the other is the anomalous transmission of electromagnetic waves over focal regions. The methods of measurement and the physical mechanisms for their generation, transmission and reception can be diverse. Therefore, close international and interdisciplinary cooperation would be vital.

Introduction

Electromagnetic study related with earthquake prediction has a long history. It was in two major streams. One was to find out some pre-seismic changes of the earth's properties, such as the electric resistivity and magnetization. The other was to detect precursory electromagnetic signals. Both are still pursued today. Here, we are mainly concerned with the latter. Sobolev (1975), Warwick et al. (1982), Gokhberg et al. (1982) are some pioneering examples, but they were not really taken seriously by the geophysical community.

The VAN method from the early 1980's has made an impact. Although far from being generally accepted, it at least generated controversies (Geller, ed., 1996: Lighthill, ed., 1996). In the early 1990's, some convincing results were reported in ultra low frequency (ULF) geomagnetic signals (Fraser-Smith et al., 1990, Kopytenko et al., 1993). The 1995 M7.2 Kobe event was a big impact, because pre-seismic electromagnetic changes in different frequency ranges from DC to very high frequency (VHF) were detected by scientists who were largely working independently and in isolation. It was probably the first case where multiple methods detected possible precursors for one earthquake.

From DC to VHF

Summary of the methods so far producing promising results may be illustrated as in Figs. 1 and 2. The electromagnetic precursory phenomena may be classified into two groups: 1) signals supposedly emitted from sources of imminent earthquake (star), and 2) anomalous transmissions of electromagnetic waves (triangle). The latter seems to require some pre-seismic ionospheric disturbances above focal regions. In the following, we will report mainly on the first group phenomena.

The VAN Method

In the DC range, the Greek VAN method (Varotsos and Alexopoulos, 1984a, 1984b) is the most advanced. It is based on the detection of characteristic changes in the geoelectric potential, the Seismic Electric Signals (SES) that appear prior to earthquakes. They consider their prediction successful when the errors in epicenter and magnitude is less than 100 km and 0.7 units, respectively, and the earthquake occurs within several weeks after SES detection.

The VAN research has made two major discoveries. One is the so called selectivity, which consists of two important contents. The first is that there are only selected sites which are sensitive to SES (sensitive sites). Lately it has become gradually clear that sensitive sites are of heterogeneous geologic structure, and close to faults.
The second is the fact that a sensitive site is sensitive only to SES from some specific focal area or areas that are not always close to them. This fact provides the means to predict the epicenter of the impending earthquake. In physical sense, the sensitive sites and corresponding focal area(s) have to be somehow selectively electrically connected.

The other important discovery of the VAN group is the relationship among the focal distance, r, M, and the observed intensity of SES. Once the epicentral area is estimated from the selectivity rule, the expected value of M can be derived from this relationship.

We have examined the performance of the VAN method as shown in Fig. 3**.** Out of 11 mb ≥5.5 EQs which occurred in the Greek region during Jan. 1, 1984 – Jan. 1, 1999, eight were predicted successfully. After the prediction of three earthquakes in 1995, there were no large events until another three mb ≥5.5 occurred in late 1997. It is remarkable that during the 2.5-year of quiescence no prediction was issued for the area and that two the three 1997 events were predicted remarkably well.

Testing in Japan

Since 1987, we have been engaged in the basic study of earthquake related electromagnetic phenomena, including testing of the VAN-method.
SES type changes have been observed before several recent earthquakes (Table 1) (Uyeda et al., 2000). In most cases, they appeared 1 - 19 days before the earthquakes. The changes appeared before five out of six earthquakes with M ≥ 5 that occurred within 20 km of our stations during the observation period. Changes were also detected at greater epicentral distances (up to 75 km) before two other events, including one M=4.7 EQ (see below). We have ascertained that no such changes occurred during the observation period, which were not followed by earthquakes. While the precursory nature of these geoelectric potential changes is admittedly unproven, it seems that the present results warrant continued serious research.

Here is an example. At 01:30 (LT) of 1999/01/17, three widely separated stations, MTS, HKB and OTA in Nagano Prefecture, Central Japan, revealed a simultaneous change lasting for 27 minutes (Figs. 4A and 4B). After 11 days, a swarm activity of more than 30 shocks, with the main shock M4.7 EQ99/01/28, occurred in the middle of the triangular area formed by the three stations (Fig. 4A). As far as this area during our observation period is concerned, EQ99/01/28 was the only M ≥ 4 EQ.

This event was unique in several aspects: 1) Simultaneous change was observed at three widely separated stations for the first time, 2) Epicentral distances to stations are larger than most other cases, the largest being 75 km (OTA), 3) The signal was not detected at other stations, such as OTW, KWI, HGW and TKC with similar epicentral distances. If the observed change was the SES of EQ99/01/28, the case is a possible example of the VAN's "Selectivity" situation.

ULF magnetic phenomena associated with earthquakes

ULF emission before and after large earthquakes was almost simultaneously discovered by Russian and American scientists about 10 years ago. ULF emission associated with the M6.9 Spitak earthquake, 1988/12/07 was discovered by Kopytenko et al., (1993). Similar phenomenon was observed in USA during the M7.1 Loma Prieta earthquake, 1989/10/17 (Fraser-Smith et al., 1990). The main characteristics of the observation can be summarized as follows:
(1) There was a broadband increase in the amplitude of emission over 12 days before the main shock.
(2) Starting three hours before the main shock there was a further considerable increase (about five times).
(3) The amplitude level at the lowest frequencies remained very high for several days after the main shock and then gradually decreased back to the background level over a time interval of several months.

At the time of M8.0 Guam Island earthquake of 1993, ULF magnetic field showed a significant increase of the ratio of SZ/SH (polarization) for about two months before the earthquake. SZ and SH are the vertical and horizontal power spectrum of the ULF change.

Fig. 5 shows the relationship between M of earthquakes and epicentral distance of ULF stations. White and black marks show the earthquakes with and without ULF anomalies, respectively. The solid line indicates the threshold for appearance of ULF signals "quasi-theoretically" derived by Molchanov et al., (1995). This figure demonstrates that if a M7 earthquake occurs, pre-seismic ULF emissions would be detected within about 100 km from the source region.

In order to establish these facts and investigate the phenomena in details, ULF magnetometers have been installed at 19 places in Japan. We have so far found several cases of appearance of ULF emissions precursory to earthquakes.

Conclusion

In order to attain short-term earthquake prediction, some precursory phenomena are necessary. By definition, they have to occur before seismometers start to shake at main shock. What is needed here is "pre-earthquake seismology", for which observation of phenomena beyond conventional seismology is useful. Among these phenomena, electromagnetic ones are highly promising.

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