International Cooperation in Pre-Earthquake Studies: History and New Directions

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ABSTRACT

Earthquake prediction must specify the time, epicenter, and size of an impending earthquake with useful accuracy. Among the long-, intermediate-, and short-term predictions, only the latter is meaningful for directly protecting human lives and social infrastructures. Globally, seismologists running national earthquake prediction projects have long been pessimistic about short-term prediction. In recent years, however, positive signs for short-term predictability are emerging from diverse scientific communities. This article is a summary of the history and new directions of international cooperation in earthquake prediction research.

Modern earthquake seismology may be said to have started in California by the advent of elastic rebound theory after the 1906 M 8.3 San Francisco earthquake [Reid, 1910]. The theory stipulates that rocks on opposite sides of a fault subjected to shear stress slowly deform until their strength is exceeded, thereby producing an earthquake. Stress is accumulated over many years but is released instantly. This idea has since been the theoretical guideline for earthquake generation. In the following several decades, however, no serious scientific attempt for earthquake prediction had been undertaken. In the 1960s, national projects for earthquake prediction started in several countries, including Japan, former USSR, China, Taiwan, and the USA. The reason why this happened more or less simultaneously is not clear. Perhaps it was because scientific activity recovered following World War II. This development was aided by the Worldwide Standardized Seismograph Network (WWSSN) for nuclear blast detection [Bolt, 1976].

In Japan, the report “Prediction of earthquakes—progress to date and plans for further development,” known as the “Blue Print” [Tsuboi et al., 1962] appeared in 1962. Its content was essentially empirical but covered all possible items for monitoring, such as crustal movements, tides, seismicity, seismic wave velocity, active faults, geochemistry, and water-level changes in boreholes, including even geomagnetism and geoelectric currents. Actual funding for earthquake prediction started in 1965 and has continued until now through consecutive 5-year plans. Russia has a similar long history of earthquake prediction, dating back to the days of the former USSR. In China, the China Earthquake Bureau (CEA) has been responsible for earthquake prediction since the late 1960s. In the USA, the National Earthquake Hazards Reduction Program (NEHRP) was proposed in 1965, but it was not until 1977 that it was authorized by Congress. Taiwan, before the 1999, Chi-Chi (or 921) M 7.3 earthquake, relied largely on fire fighters, police, and military at emergencies or natural disasters. After the 1999 earthquake, they established a permanent search-and-rescue team and an early-warning system.

The International Commission on Earthquake Prediction was set up 1967 under the auspices of the International Union of Geodesy and Geophysics.
The IUGG is the world’s largest organization of geophysics. Optimism prevailed globally [Press, 1975] in the early 1970s due, for instance, to the apparent success of the dilatancy diffusion model [Sholtz et al., 1973], which appeared to explain all the precursory phenomena such as anomalous uplift, seismic-wave velocity change, etc. Dilatancy is the volume increase due to generation of microfractures under high stress and diffusive influx of water into them was considered as the cause of lowering of rock strength, facilitating earthquakes. The success of long-, intermediate-, and short-term predictions of the 1975 *M* 7.3 Haisheng earthquake also boosted optimism, but that optimism proved ephemeral. The seismic-wave velocity changes predicted by the dilatancy diffusion model were not supported by accurate measurements in California [McEvilly and Johnson, 1974] and the CEA failed to predict the 1976 *M* 7.8 Tangshan earthquake [Chen et al., 1988]. In the USA, the Parkfield earthquake, predicted to occur before 1993, did not occur until 2004 [Langbein et al., 2005]. In fact, no internationally accepted prediction by any national earthquake prediction projects proved successful. This led to a totally pessimistic outlook, not only by scientific and social communities but also by governments, and this pessimism [Everdén, 1982] has essentially lasted until today. The 2011 *M* 9 Tohoku-Oki earthquake occurred during the seventh five-year prediction research program, after which the seismological communities in Japan completely gave up official short-term earthquake prediction research.

During the same period, mainly in the 1970s, the plate tectonics concept became established. As is well established, according to plate tectonics theory, Earth’s surface layer is composed of about ten slowly moving (<10 cm year\(^{-1}\)) plates (<150 km thick) and their interactions cause the whole range of tectonic processes observed, from mountain building to earthquakes [e.g. Uyeda, 1977; Turcotte and Schubert, 1982]. For geoscientists, including seismologists naturally, plate tectonics was an eye opener towards a more global view, as seismologists became to see that seismicity in their own country is part of a global network of activity. This helped promote “international cooperation.”

In spite of this general trend, because they could not identify reliable precursors, seismologists maintained a negative attitude towards earthquake prediction. In Japan, most resources of national projects were spent on improvements to seismic networks rather than on acquisition of precursory phenomena data, which usually requires monitoring of nonseismic physical quantities. Throughout this long period of general pessimism, however, some fervent scientists in many countries continued their positive efforts. For instance, the VAN method (named after its originators P. Varotsos, K. Alexopoulos, and K. Nomicos) of short-term prediction has been practiced in Greece over the past several decades. This method is based on the observation of low-frequency transient changes of Earth’s electric field, called seismic electric signals (SES), that precede earthquakes, enabling forecast of the parameters (epicenter, magnitude, and time window) of impending earthquakes [Varotsos and Alexopoulos, 1984; Varotsos et al., 1986].

As described by M. Hayakawa in Chapter 2, the main focus of these efforts was on the electromagnetic precursors. Electromagnetic study of earthquakes had been initiated in Japan in the early 1980s [Gokhberg et al., 1982] using very low-frequency (VLF) and LF electromagnetic emissions. It should be noted, however, that the seismo-electromagnetic groups in Japan were funded only once, just after the 1995 Kobe earthquake, but this could be considered as the start of extensive precursor studies [Nagao et al., 2002], and may have inspired seismo-electromagnetic studies in other countries such as Taiwan, Russia, and Italy. Two Japanese institutions were asked to conduct feasibility studies of electromagnetic effects on short-term earthquake prediction for a period of 5 years (1996–2001): (a) RIKEN (Institute of Physical and Chemical Research) and (b) NASDA (National Space Development Agency of Japan, now JAXA) in the Earthquake Integrated Frontier framework of the Science and Technology Agency (now MEXT). The RIKEN project was led by S. Uyeda and the NASDA project by M. Hayakawa.

The RIKEN group installed about 40 VAN type geoelectric stations all over Japan. They found geoelectric signals before *M* > 5 earthquakes [Uyeda et al., 2000], but they also found that Japan is not suitable for the VAN method because of noise from DC electric trains. The stations did, however, detect very significant precursors of DC and ultra-low frequency (ULF) electric and magnetic radiation before the volcano-seismic activity in 2000 in the Izu island region where there is no DC-driven electric trains [Uyeda et al., 2002].

Nowadays active research is carried out using the ULF to VHF bands in many countries. Among others, a possible new type of preseismic change of the ionosphere [Heki, 2011; Kamogawa and Kakinami, 2013; Heki and Enomoto, 2015] may be noteworthy. Lithosphere-atmosphere-ionosphere coupling (LAIC) [Kuo et al., 2014; Pulinets et al., 2015] and thermal radiation anomalies [Ouzounov et al., 2011] are also important approaches in this field, and these will be thoroughly treated in later chapters of this book.

In 1996, CNES (Centre National d’Etudes Spatiales) began to develop microsatellites: DEMETER (detection of electro-magnetic emissions transmitted from earthquake regions), launched in 2004, is the pioneer of this international project. Using DEMETER, it was found that nighttime VLF emission markedly decreases in the 4h before *M* > 4.8 earthquakes [Nemec et al., 2008]. China, in cooperation with Italy, plans to build a fleet of...
electromagnetic satellites by launching one every few years from 2017.

In July 1999, the general assembly of the IUGG was held in Birmingham, UK. In one of its sessions, extremely active discussion was held not only on electromagnetic signals but also on their physical mechanisms and it was decided to establish a Working Group on Electromagnetic Study of Earthquakes and Volcanoes (EMSEV). The EMSEV was founded by the IUGG in 2001 as an Inter-Association Working Group belonging to IAGA (International Association of Geomagnetism and Aeronomy), IASPEI (International Association of Seismology and Physics of Earth’s Interior) and IAVCEI (International Association of Volcanology and Chemistry of Earth’s Interior). This “Inter-Association” Working Group clearly establishes EMSEV as an international multidisciplinary team.

Establishing EMSEV was the dawn of both new earthquake prediction research and “International Cooperation”. The first meeting of EMSEV was in 2002 in Moscow. Since then, international EMSEV meetings have been held every 2 years: France (2004), India (2006), Romania (2008), USA (2010), Japan (2012), Poland (2014), and China (2016). The next meeting will be in Italy (2018): For details see http://emsev-iugg.org/emsev/. The EMSEV Working Group have also organized special sessions at IUGG international meetings: Japan (2003, Sapporo), Italy (2007, Pergia), Australia (2011, Melbourne), and Czech Republic (2015, Prague), as well as at a diverse array of international meetings organized by IAGA, IAVCEI, and IASPEI (Iceland, Japan, Mexico, South Africa, Hungary) and regional workshops (Philippines, Kyrgyzstan, Greece, France).

In conclusion, we would like to draw your attention to the recent remarkable revival of seismology in earthquake prediction research, which has now emerged from the shadows of electromagnetic research. Examples include the study on earthquake generation using spatial organization of foreshocks [Lippiello et al., 2012] and the possible role of slow earthquakes on the generation of huge earthquakes [Obara and Kato, 2016]. Perhaps, now is the time to discard the long-held pessimism and combine all our forces to venture towards transforming precursor information into practical earthquake prediction.

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