Analysis of foreshock sequences in the Iranian plateau

SnT 2021 CTBT: SCIENCE AND TECHNOLOGY CONFERENCE 28 JUNE TO 2 JULY

Poster No. P1.2-188

Amir Mansour Farahbod, PhD
Mania Sabouri, MSc

Abstract

We analyze foreshock activity in the Iranian plateau by investigating the occurrence patterns for isolated M >= 5.5 earthquakes from 1968 to 2018. Among the 165 mainshocks with M >= 5.5 (after excluding 12 aftershocks, 6 swarms and 9 doublets), 18 percent are preceded by at least one foreshock within 30 days and 20 km. However, the number of events in each foreshock sequence is significantly higher in the last ten years of the catalog. This difference is partly explained by the rapid expansion of the Iranian national seismographic network in the recent years. Based on our analysis, the completeness magnitude of the catalog is declined over years and reached to 3.4 (2008-2018) from 5.1 (1968-1998). Foreshock occurrence appears correlated with mainshock faulting type and depth; however, it is not correlated with mainshock magnitude. These results suggest that foreshock occurrence is largely controlled by the regional tectonic stress field and fault zone properties. In special cases, foreshock activity is considered as one of the most promising precursory changes for the main shock prediction in the short term; however, foreshock properties are not reliably predictive of the magnitude of the eventual mainshock.

Introduction

In an earthquake sequence, foreshocks are earthquakes that occur prior to the mainshock. The foreshock activity often shows significant differences compared with the ordinary seismic activity such as a decreased b-value (Tormann et al. 2015) and migration and acceleration prior to the mainshock (e.g., Marsan et al. 2014). Temporal distributions of foreshocks are quite variable. Mogi (1985) classified the foreshock sequences into two types, C and D. In type C sequences, the activity increases gradually toward the mainshock. In type D sequences, the mainshock occurs after the foreshock activity dies down. Although no detailed statistics are available, type D seems to form a majority of foreshock sequences.

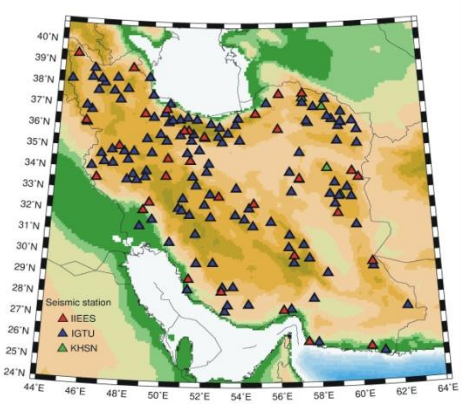
A point of controversy, however, is the definition of the short-term foreshocks and the recognition of foreshocks in seismic catalogues strongly depends on the definition adopted. Spatiotemporal restrictions may exclude foreshock events occurring outside the preselected narrow space-time limits, thus leading to biased results. Pre-selected foreshock definitions may partly explain why only some mainshocks are preceded by the short-term foreshocks. On the other hand, the occurrence of foreshocks very likely depends on a variety of geophysical factors, such as the style of faulting, the focal depth, and the degree of small-scale crustal heterogeneity (Cheng and Wong 2016). The completeness of the catalogue is also an important factor. In seismic catalogues, particularly the ones produced by routine procedures, small foreshocks usually are overlooked and are not catalogued (Papadopoulos et al. 2006). To use foreshocks as a potential tool for the short-term earthquake prediction, it is of great importance to discriminate between foreshocks and other types of seismicity clusters, e.g., swarms and main shock-aftershock sequences, which again depends on the foreshock definition.

History of earthquake monitoring in Iran

Institute of Geophysics of the Tehran University (IGTU) established the first modern seismic station of Iran in 1958 in Tehran to monitor the seismicity around the capital. In 1960s, the number of IGTU seismic stations increased to six, including one local station in Sefid-Rud dam (1962) and four others in Shiraz (opened in 1963/05), Kermanshah (opened in 1965/04), Tabriz (opened in 1965/08) and Mashhad (opened in 1965/09). Three stations in Tabriz, Mashhad and Shiraz were a subset of the World-Wide Standardized Seismographic Network (WWSSN). In January 1976, the Iranian Long Period Array (ILPA) comprised of seven wideband borehole seismometers began its operation in southwest of Tehran (Akasheh et al., 1976). ILPA is considered as the first digital/analogue seismic recording facility in the country which was operational until the early 2000s. Also, in the early 1980s five new IGTU analogue recording stations were opened in Brojen, Minoodasht, Mahabad, Ghamsar-e-Kashan and Ghaleh-Ghazi.

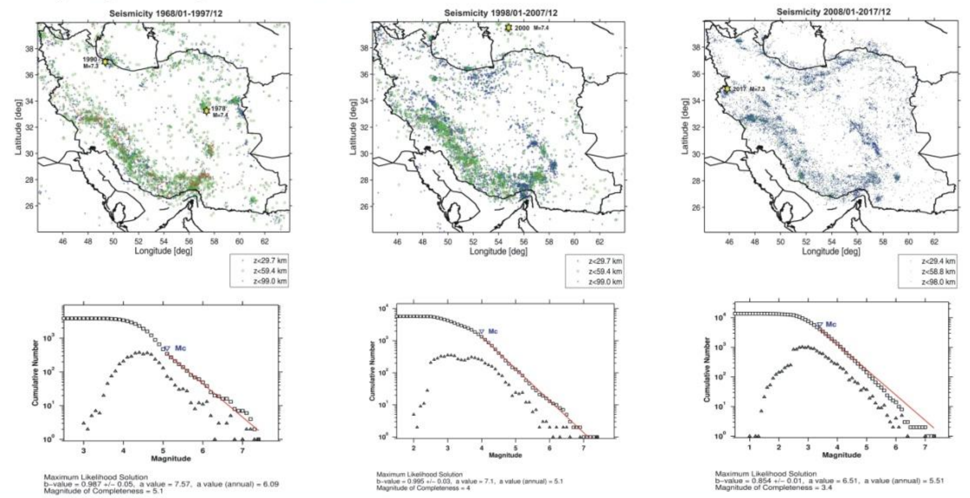
The era of digital seismography in Iran was started in 1996 by the completion of two telemetric local networks around the large cities of Tehran and Tabriz. Seismic stations were equipped with three component short-period, medium-band or broad-band seismometers. Today, the Iranian seismological network (operated by the IGTU) is comprised of 20 local networks with 135 seismic stations (in total) which covers most of the earthquake-prone regions of the country.

In addition to the IGTU seismic network, International Institute of Earthquake Engineering and Seismology (IIEES) that was founded in 1989 operates 34 seismic stations equipped with broadband sensors. Also a provincial network of eight stations (KHSN) in northeast of Iran is maintained by the Ferdowsi university of Mashhad.



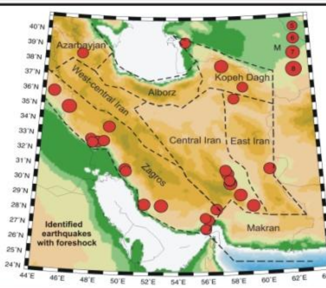
Data and Analysis

We search for isolated mainshocks with M >= 5.5 using three catalogs that exclusively dedicated to earthquakes in the Iranian plateau including the national (IGTU) catalog, IIEES catalog and the revised catalog of Farahbod & Alahyarkhani (2000). M is the homogenous estimate of moment magnitude (Kishida et al., 2019). Magnitude of completeness (Mc) of the compiled catalog is estimated (Zmap; Wiemer 2001) between 5.1 (1968-1998) and 3.4 (2008-2018). To reduce potential catalog incompleteness issues for smaller earthquakes and as a compromise, we use events with M >= 3.0 in this study. We select mainshocks that are relatively isolated from other large events, i.e., events that are not part of aftershock sequences or immediate foreshocks of larger events. In this regard, we exclude earthquake swarms and doublets (two events of similar magnitude occurring almost instantaneously). Considering foreshock characteristics of a few documented cases in the past, we define foreshocks in this study as immediate precursory activity within 30 days and 20 km of the mainshock.



Results

Among the 165 mainshocks that we identified from 1968 to 2018 with M >= 5.5 (after excluding 12 aftershocks, 6 swarms and 9 doublets), 18 percent are preceded by at least one foreshock within 30 days and 20 km. However, the number of events in each foreshock sequence is significantly higher in the last ten years of the catalog due to the declining trend of Mc. Magnitude of the identified "single foreshock" in our database varies between 3.1 and 5.5. In terms of the location distribution, identified earthquake sequences are distributed in the majority of the most active tectonic zones of the country.



Conclusions

In the Iranian plateau most of the tectonic displacement is accommodated by the Zagros mountain belt, through strike-slip faults in Central Iran, the shortening of the Alborz mountain in the north, the shortening across the eastern Kopeh Dagh in the northeast, and the Makran subduction zone in the southeast. Considering the limited time window of this study (50 years), incompleteness of the compiled catalogue (specifically in the first 30 years) and relatively high location uncertainty of the events, we conclude that foreshock activity in the Iranian plateau is largely controlled by the regional tectonic stress field and fault zone properties.

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