

UDC 550.34

STUDIES OF REPEATING EARTHQUAKES IN CHINA**D.P. Schaff, P.G. Richards***Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York, USA*

The data on repeating earthquakes occurred in and near China and revealed by studying local and regional events using Annual Bulletin of Chinese Earthquakes (ABCE) for the period from 1985 to 2005 has been provided. Repeating earthquakes may be used in studying earthquakes physics and in qualitative estimation in locating events.

Seismograms from moderate earthquakes with magnitudes about 6 and smaller are typically quite complicated when recorded at distances of several hundred km or more. But yet it is found that such waveforms are sometimes repeated, in detail, in the signals from other earthquakes recorded at the same stations (e.g. Kaufman and Burdick, 1980). In this paper we report on thousands of examples of such repeating seismic events occurring in mainland East Asia, with a focus on data from stations in and near China. These events represent a significant fraction of all recorded seismicity in the region, and it is accepted that repeating events must have occurred close to each other, within a distance that depends upon the details of similarity of the seismic waveforms they generate, as documented by stations that recorded both events.

Repeating seismic events are studied for what they can tell us about earthquake source physics, since the data from such events may contain information about their proximity. For example, there is interest in whether the rupture zones of repeating earthquakes overlap (or not) and interest too in the patterns of changing stress, inferred from event sizes and the rate of event repetition. To the extent that waveforms may be highly similar but not exactly repeated, repeating events are studied also for what they may reveal about slight changes in the medium through which the signals propagate. And a third broad reason for studying repeating events, is to evaluate the precision of traditional methods for estimating locations and amplitudes of seismic events. It is this last reason, which is of particular interest to organizations engaged in monitoring for nuclear explosions using seismological methods.

But before any of these uses of repeating earthquakes can be explored, repeating events have to be found. We need to get a sense of how common they are at different magnitude levels, and a sense too, of how their frequency of occurrence changes over time. Does the occurrence rate depend significantly upon magnitude level, and does it rise or fall or stay the same when we search for repeat events over longer and longer time periods?

We report on the occurrence of repeat earthquakes, as discovered by application of cross-correlation methods to waveform archives. Such work is different from uses of cross-correlation to measure specific features such as relative arrival times of pairs of events, for

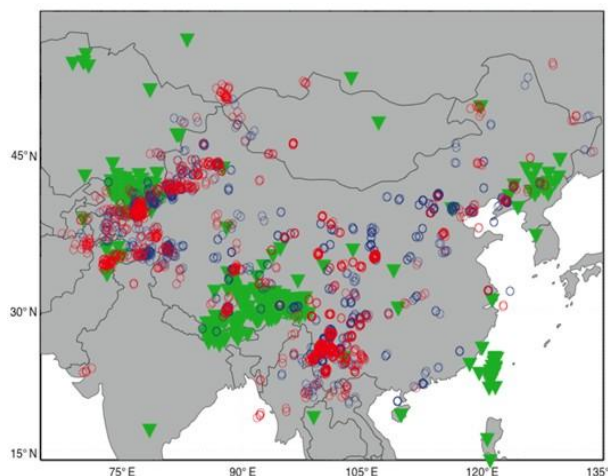
example for purposes of event location see Schaff and Waldhauser (2005). It is different too from using cross-correlation to detect events. In both those cases, useful values of the cross-correlation coefficient can be quite low. Our focus in this paper, is on sets of events that turn out to have very high waveform similarity.

Below, we describe our data and basic technique for finding repeat events. We then use the many repeat events found in mainland East Asia over a 21-year period to assess mislocation of seismic events as reported in bulletins that use traditional methods.

DATA AND METHOD OF ANALYSIS

This project is a follow-up to the search for repeating events, in and near China, reported in Schaff and Richards (2004), which covered the years from 1985 to the beginning of 2000. We have updated it with six additional years using the Annual Bulletin of Chinese Earthquakes (ABCE) so that it now covers the 21 years up through 2005. The catalog contained 22,513 events in and near China for this time period of which 17,898 events had usable waveforms recorded at 363 stations archived at Data Management Center of the IRIS Consortium, amounting to 110 Gb of data. The same criteria was used as in Schaff and Richards (2004) to define a repeating event pair: windows including the entire seismogram starting 5 s before the *P*-wave and ending 40 s after the *Lg*-wave were filtered from 0.5 to 5 Hz. A threshold for the cross-correlation coefficient (CC) of 0.8 or greater was used to identify the repeats. All event pairs with separation distances less than 150 km were searched, amounting to 24 million correlation measurements. To speed up the computations, events were read in all at once in 200 km intervals of distance from the station. The ending cut-time, 40 s after the *Lg*-wave, is based on the group velocity of 3.5 km/s and these 200 km intervals, not for each individual pair.

Figure 1 displays the results. 2379 events out of the 17,898 or 13% were classified as repeats. This contrasts to the earlier work, which found 1301 repeat events or 9% for the earlier time period. The old events are plotted as blue circles. The newly discovered repeats are in red. Both are well-distributed throughout China. The stations used are shown as green triangles.



Events from an earlier study (Schaff and Richards, 2004) are in blue. New events are in red. Green triangles are stations that recorded waveforms

Figure 1. Map of 2379 repeating seismic events in and near China

Figure 2 shows how the cumulative number of repeats, which increased in both the prior and current studies as a function of calendar time. Closer examination of early years revealed that data glitches that were not caught caused some repeats to mistakenly be identified in the prior study. But even with the removal of these events, the percentage of the total number of repeats is still higher because of the steeper slope for later years, presumably due to the increased station coverage.

Schaff and Richards (2004) showed that the separation distances of events that met the above criteria was no more than 1 km. This feature allows an independent determination of relative location error for various catalogs, which is of prime interest for many purposes in seismic monitoring. Table 1 summarizes the statistics of our repeating events as reported for three bulletins: the ABCE; the bulletin of the International Seismological Centre; and the Reviewed Event Bulletin of the Comprehensive Nuclear-Test-Ban Treaty. The number of unreported events is

recorded for the time periods where the bulletins are available: ISC (1985 through 2005, which is the whole time period), REB (1995 through 2005--noting that until February 2000 the REB was produced in the USA by a prototype of the CTBT Organization's data centre). The mislocation statistics are an average for the whole time period studied. In practice we have found that mislocation values for the REB have tended to reduce over time. When the primary network of International Monitoring System stations is complete in East Asia, location accuracy can be expected to improve.

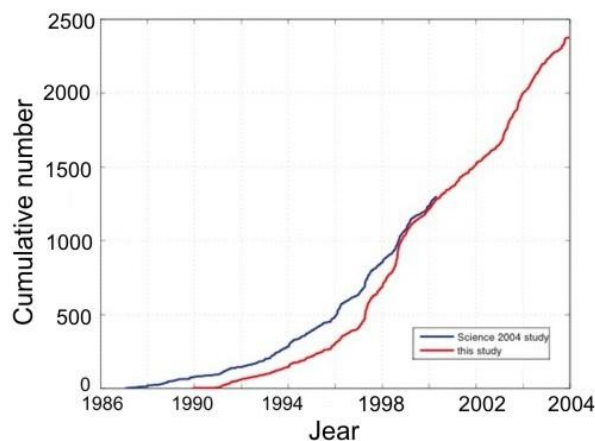


Figure 2. Cumulative number of repeating events vs. calendar time. Year label is at the beginning of the year

RECURRENCE INTERVALS

The very definition of a repeating event is a similar earthquake, which occurs in almost the same spot at a later time. This is a concept leading naturally to an interest in measurements of recurrence intervals. We find that the median interval between repeating events is about 8 days in the present case. Table 2 breaks this down further in terms of different intervals. We find that 22% of the doublets occur within a day of each other.

Table 1. Statistics for 2379 repeating seismic events, in and near China, 1985 to 2005

	ABCE	ISC	REB
Median (km)	16	16	18
Mean (km)	23	22	31
Max (km)	142	234	281
Number of doublet pairs	2178	671	492
Number of observations	6326	2297	1768
Number of events	2379	1168	912
Number of unreported events	0	1211	1248
Percentage of unreported events	0	51	58
Number of $M 2$ events	151	missed 149	missed 149
Number of $M 3$ events	1444	missed 990	missed 1001
Number of $M 4$ events	725	missed 68	missed 97
Number of $M 5$ events	41	missed 0	missed 1
Number of $M 6$ events	2	missed 0	missed 0

Table 2. Recurrence interval statistics for 2178 doublet pairs

	1 day or less	1 day to 1 week	1 week to 1 month	1 month to 1 year	1 to 2 years	2 to 5 years	5 to 11 years
Number	487	407	297	572	180	186	49
% of doublets	22	19	14	26	8	9	2
Cumulative %	22	41	55	81	89	98	100

With general seismicity there is a magnitude-dependence to recurrence interval. In a given area, a Gutenberg-Richter magnitude frequency distribution requires that for a certain time period there will be a much greater number of smaller events compared to the number of bigger events. The underlying reason is that it takes more time for stress to reload a fault so that larger events occur.

CONCLUSION

Doublet events provide a means to evaluate the quality of event location estimates. For the 2178 doublets we have identified in the Annual Bulletin of Chinese Earth-

quakes from 1985 to 2005, the medium, mean, and maximum separation distances are 16 km, 23 km, and 142 km respectively. 1168 of these doublets in and near China are also reported by the International Seismological Centre, and for these ISC doublets the corresponding separation distances (median, mean, maximum) are 16, 22, and 234 km. The Reviewed Event Bulletin of the Comprehensive Test Ban Treaty Organization includes 912 of these doublets in and near China, and the corresponding separation distances for the REB are 18, 31, and 281 km.

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ҚЫТАЙДАҒЫ ҚАЙТАЛАНАТЫН ЖЕРСІЛКІНУЛЕРІН ЗЕРДЕЛЕУ

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1985 - 2005 ж.ж. үшін Жыл сайынғы қытайлық жерсілкінулер бюллетеньдері бойынша жергілікті және аумақтық оқиғаларын зерделеу негізінде Қытай мен оның шекарасына жақын аумақтарда анықталған қайталанатын жерсілкінулер туралы деректері келтіріледі. Қайталанатын жерсілкінулері жерсілкінулердің физикасын зерделу, сондай-ақ оқиғаларды окшаулау сапасын бағалауына құралы болу мүмкін.

ИЗУЧЕНИЕ ПОВТОРЯЮЩИХСЯ ЗЕМЛЕТРЯСЕНИЙ В КИТАЕ

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Приводятся данные о выявленных повторяющихся землетрясениях на территории Китая и вблизи его границ на основе изучения локальных и региональных событий по Ежегодным бюллетеням китайских землетрясений за 1985 – 2005 гг. Повторяющиеся землетрясения могут служить средством изучения физики землетрясений, а также для оценки качества локализации событий.