Monitoring of deep slip rate in a creeping fault: From 2012 to 2021

NTNU Earth Sciences

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Introduction

Repeating earthquake sequence (RES) is a group of earthquakes with nearly identical seismic signatures such as: magnitude, location, and focal mechanism. RES is able to accumulate strain and rupture the fault patch repeatedly. With the same station, path, and source effect, RES share similar waveforms. The waveform similarity is often used as a way to detect RES. Due to the regular recurrence of RES, it is regarded as one of the important means of fault zone monitoring.

In this study, we aim to: (1) update the M>3 RES catalog from 2012 to 2021. (2) Use the latest result to obtain the slip rate of the faults in Taiwan.

Data and method

To update the catalog, we need 2 kinds of data: first is the RES catalog from Chen et al (2019) which includes RES in Taiwan from 2000 to 2012. Another one is the earthquake catalog and waveform, we use the earthquake catalog from Central Weather Bureau (CWB) to update the catalog and waveform from Institute of Earth Sciences (IES) for cross-correlation.

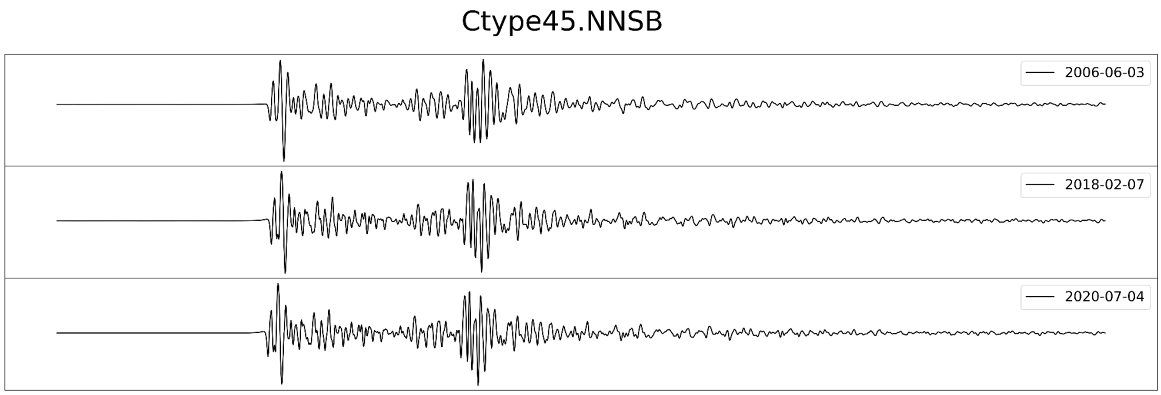


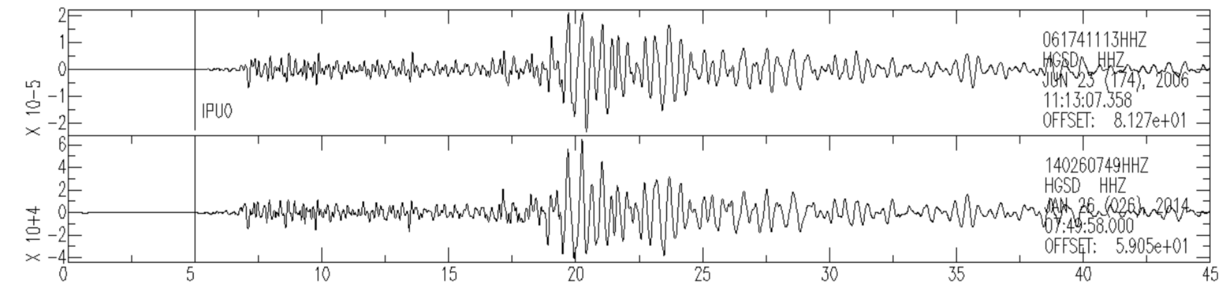
Figure 1. One of the RES waveform examples, we can see the waveforms are highly similar.

To update the RES catalog, we first obtain the waveform data from the Institute of Earth Sciences. After preprocessing, we calculate the cross-correlation coefficient

(CCC) between new earthquakes to 62 sequences. If the CCC value is higher than 0.7 at more than 3 stations. We add the event to the sequence.

Even after cross-correlation and the thresholds, some waveforms are not quite similar. Thus, we need to do the visual inspection for double check. As the example(Figure 2), the waveform below will be excluded from the ccc result.

(a)



(b)

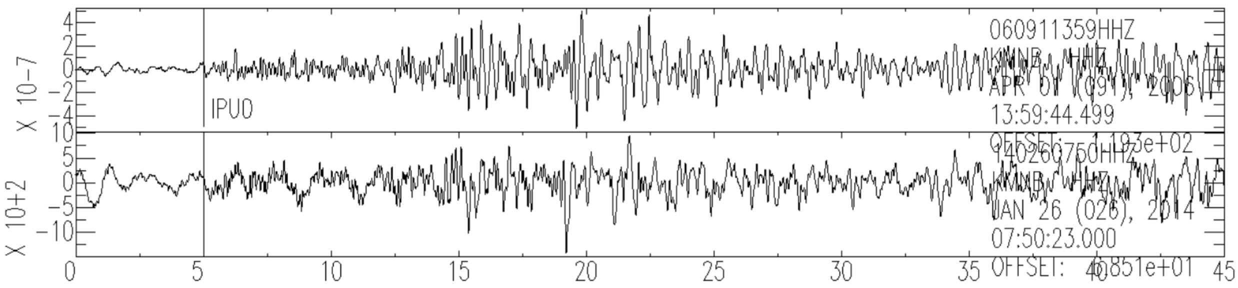


Figure 2. (a) CCC=0.991, (b) CCC=0.75. You can see in (b), although the CCC>0.7, the waveform is not similar at all.

Results

After identification, we obtain 447 repeating earthquake events from 2000 to 2021 (Figure 3a), magnitude(ML) ranging from 2.8 to 4.6. The left figure shows the distribution of 447 events.

We found the average amount of repeating events decreased after 2012 from 27.4 to 13.1 events/year (Figure 3b). However, the background seismicity rate of ML>3 earthquakes shows only a small change from ~1500 to ~1400 events/year (Figure 3c). This indicates the change of the RES rate is not a result of reducing background seismicity.

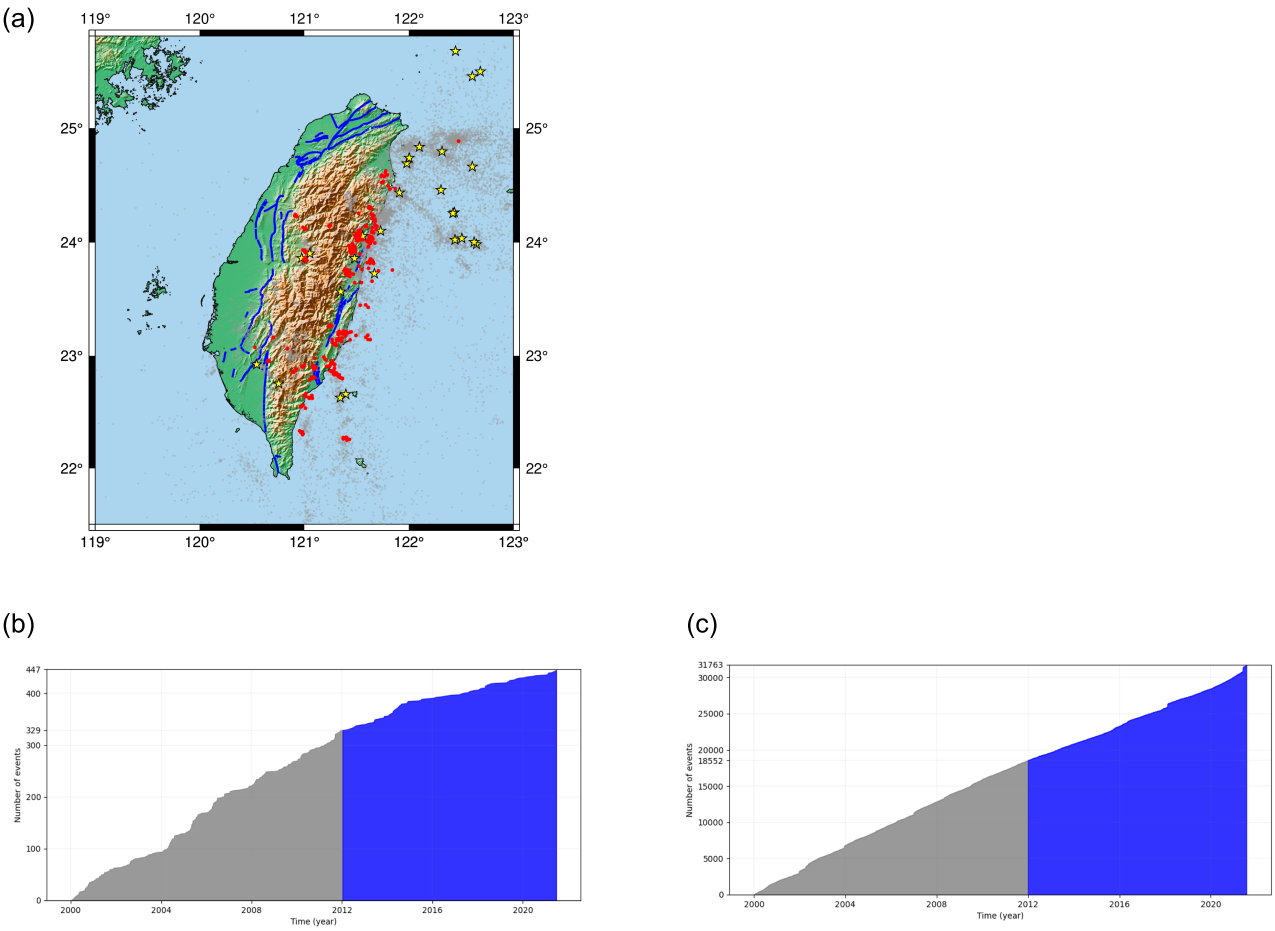


Figure 3. (a) Red dots are the repeating events. Gray dots are background seismicity. Yellow stars are earthquakes ML>6. (b) The event amount before 2012 is 329, and the event amount from 2012 to 2021 is 118. (c) The event amount before 2012 is 18552, and the event amount from 2012 to 2021 is 13211.

Recurrence interval of RES

To obtain the slip rate of the fault patch from RES, recurrence interval (Tr) and magnitude play important roles. Recurrence interval is the time between 2 earthquakes in the sequence.

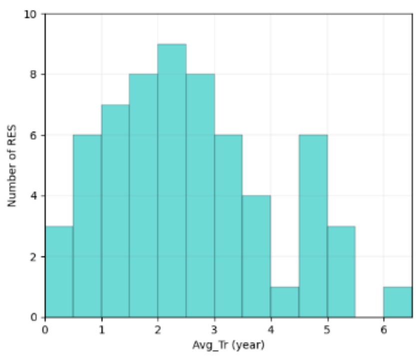


Figure 4. We found that most of the recurrence intervals are shorter than 4 years.

Distribution of RES

The RES are mainly located in eastern Taiwan, so we separated into the two areas, Chihshang (Figure 5a) and Hualien (Figure 5b) by 23.3°N (Chen et al., 2019). The amount of RES in Chihshang and Hualien are 16 and 30 sequences including 107 and 252 events. The total amount of RES in eastern Taiwan accounts for ~80% of the RES.

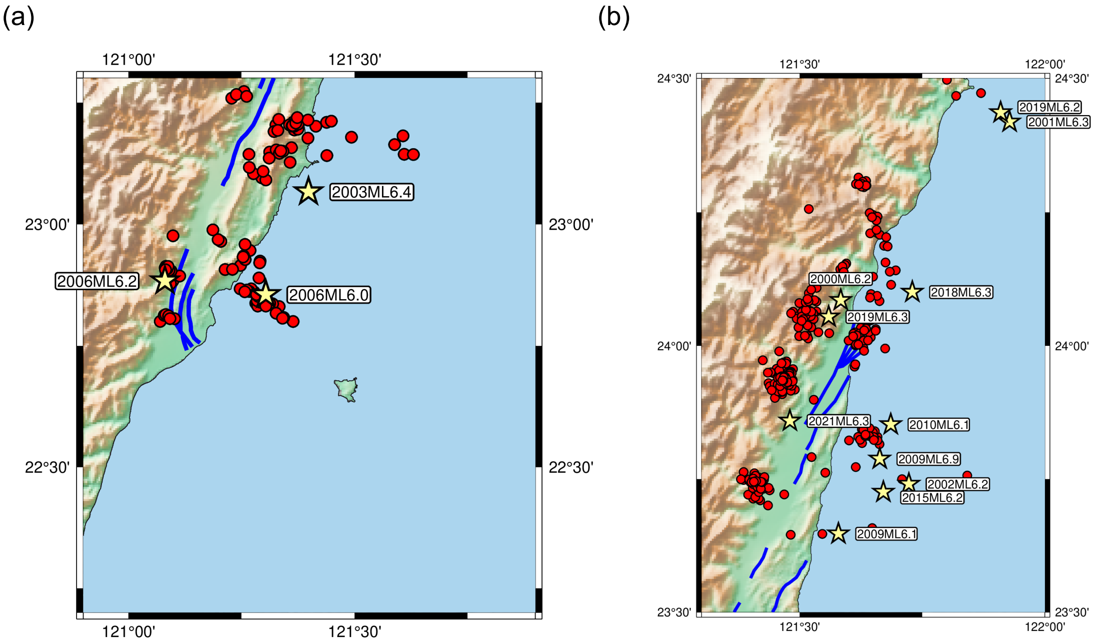


Figure 5. Red dots are the repeating events. Yellow stars are earthquakes ML>6. (a) Shows the repeating events in Chihshang. (b) Shows the repeating events in Hualien.

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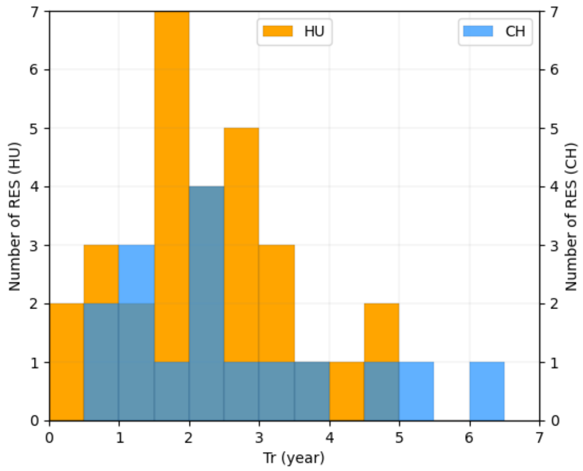
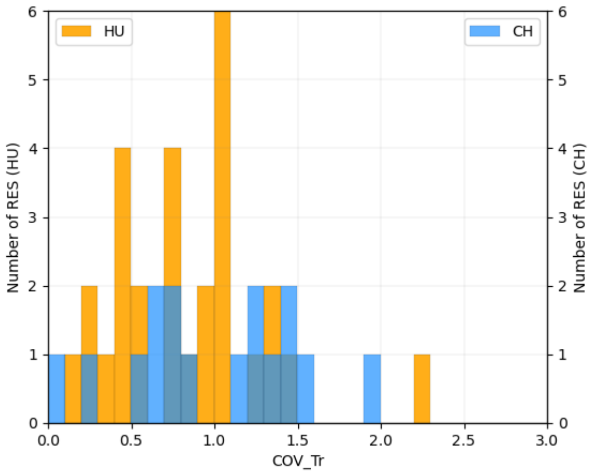
When we look into the Chihshang and Hualien area, the comparison of magnitude (Figure 6a), recurrence interval (Figure 6b), and coefficient of variation of recurrence interval (Figure 6c).

The average magnitude is 3.3 in both Chihshang and Hualien, the average recurrence interval (Tr) in Chihshang is 2.06, Hualien is 2.22, and the coefficient of variation of recurrence interval (COV_{Tr}) in Chihshang is 0.94, Hualien is 0.99. We found that the average magnitude are the same, the average recurrence interval is higher in CH, and the coefficient of variation of recurrence interval is similar.

(a)



(b)



(c)

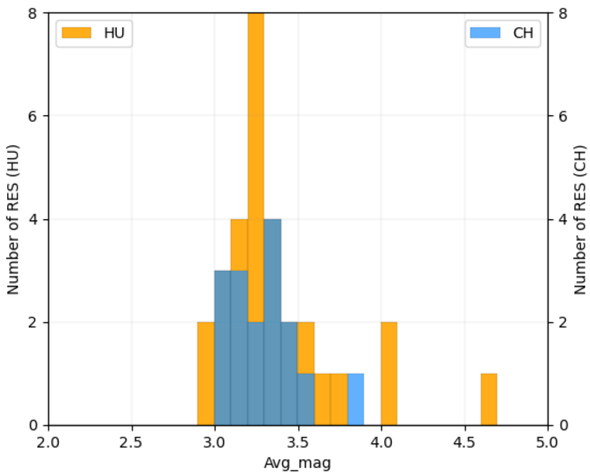


Figure 6. Chihshang area is blue and Hualien area is orange, the comparison of (a) average magnitude, (b) recurrence interval, and (c) coefficient of variation of recurrence interval.

Slip calculation

We first use the relationship to change local magnitude (*ML*) into seismic magnitude (*Mw*) (Chen et al., 2019):

$$Mw = 0.91ML - 0.07$$

Then we use the relationship to change seismic magnitude (*Mw*) into seismic moment (*Mo*) (Chen et al., 2019):

$$\log Mo = 1.5\ (Mw + 10.73)$$

The relationship was investigated by Nadeau and Johnson (1998) using the 55 RES along San Andreas fault (SAF).

$$\log d = \alpha + \beta \log Mo$$

Chen et al (2019) update the coefficient using RES in Taiwan:

$$\text{CH: } \alpha = -1.21\text{、}\beta = 0.11$$

$$\text{HU: } \alpha = -1.96\text{、}\beta = 0.14$$

We use these 2 equations to calculate the slip in each area:

$$d = 10\text{^}(-1.21 + 0.11\log Mo)$$

$$d = 10\text{^}(-1.96 + 0.14\log Mo)$$

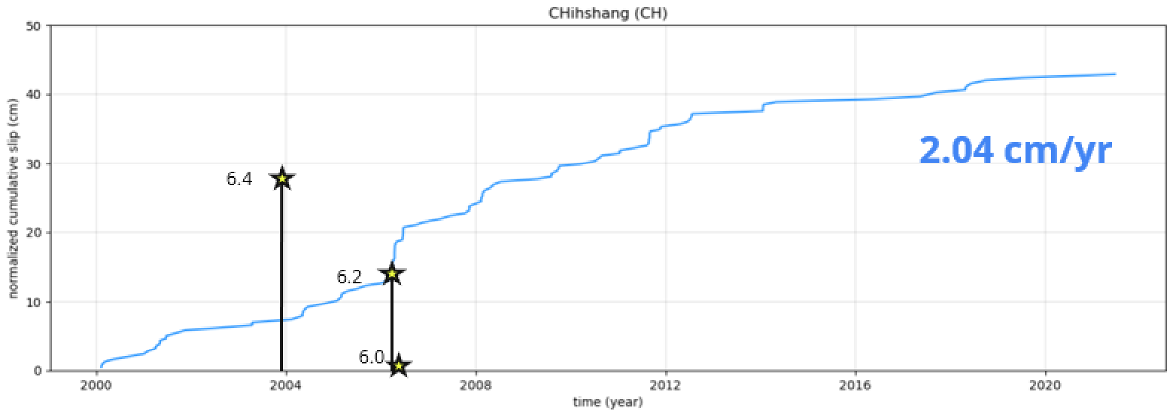
At last, we will use the slip (d) we got to calculate the slip rate.

Average slip rate

We first transfer the magnitude to slip using the equation mentioned before. And normalized by the sequence amount in each area. Chihshang is 16, and Hualien is 30. Then we divided slip by year to get slip rate.

In Chihshang, the slip rate is 2.04 cm/yr (Figure 7a). And we found that the slip behavior is influenced by the 2006 event. The slip rate increased immediately after the mainshock. In Hualien, the slip rate is 2.15 cm/yr (Figure 7b). Although the M>6 earthquakes are within the RES area, the slip rate remains stable and not influenced by the earthquakes.

(a)



(b)

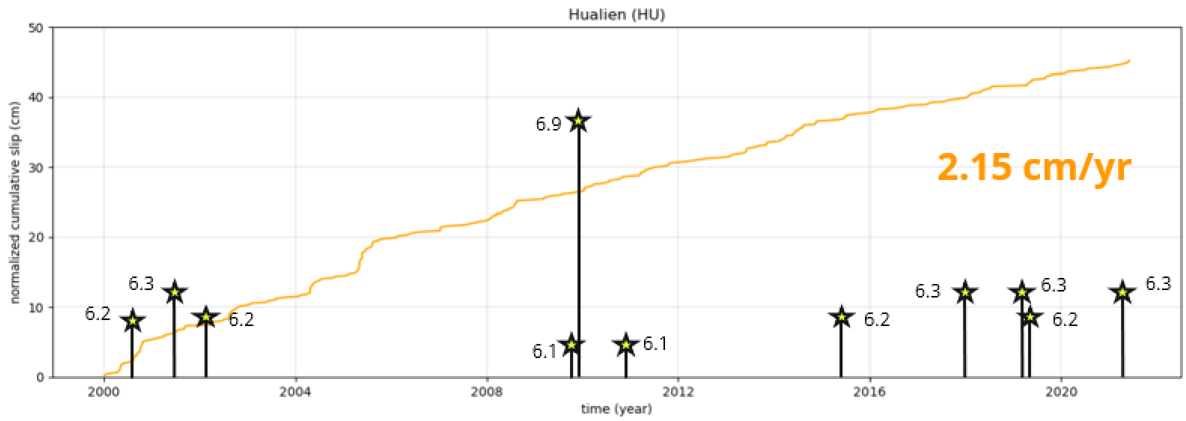


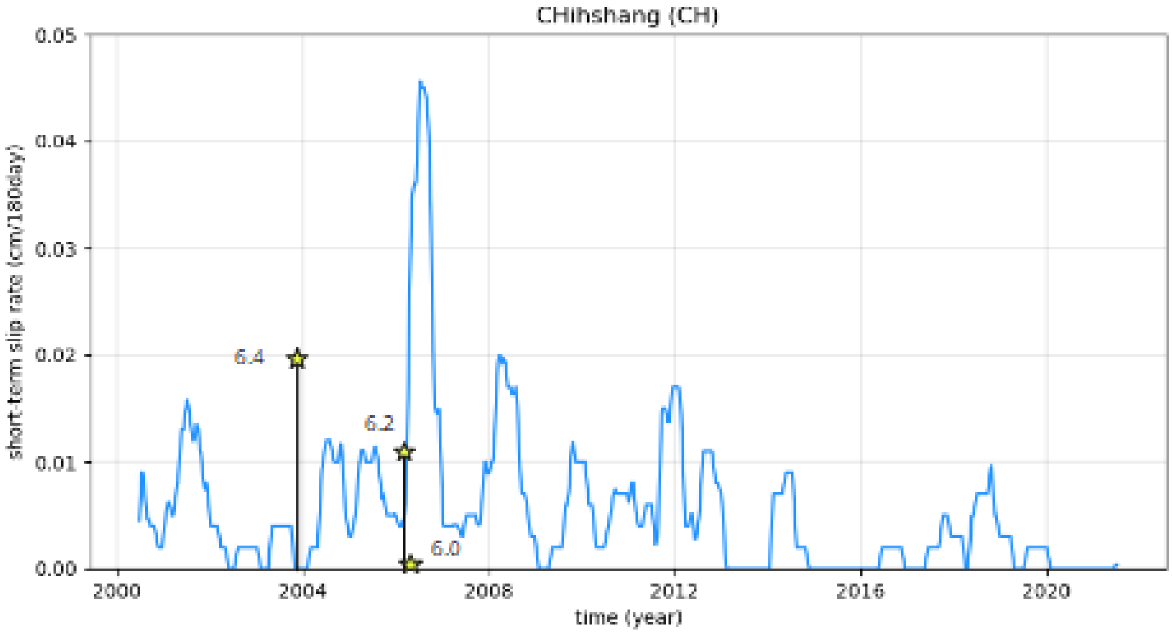
Figure 7. We normalized the cumulative slip, the yellow star (ML>6 earthquakes) in both figures, you can see the distribution in figure 5. (a) Shows the cumulative slip in Chihshang, and (b) shows the cumulative slip in Hualien.

Short-term slip rate

Except the average slip rate. We also calculate the short-term slip rate by using the moving window average. The short-term slip rate is calculated using the 180-days window and the one day step.

So the short-term slip rate is the cumulative slip of 180 days before each day divided by 180 days and normalized by the sequence amount in each area, and we will get the average short-term slip rate of each area.

(a)



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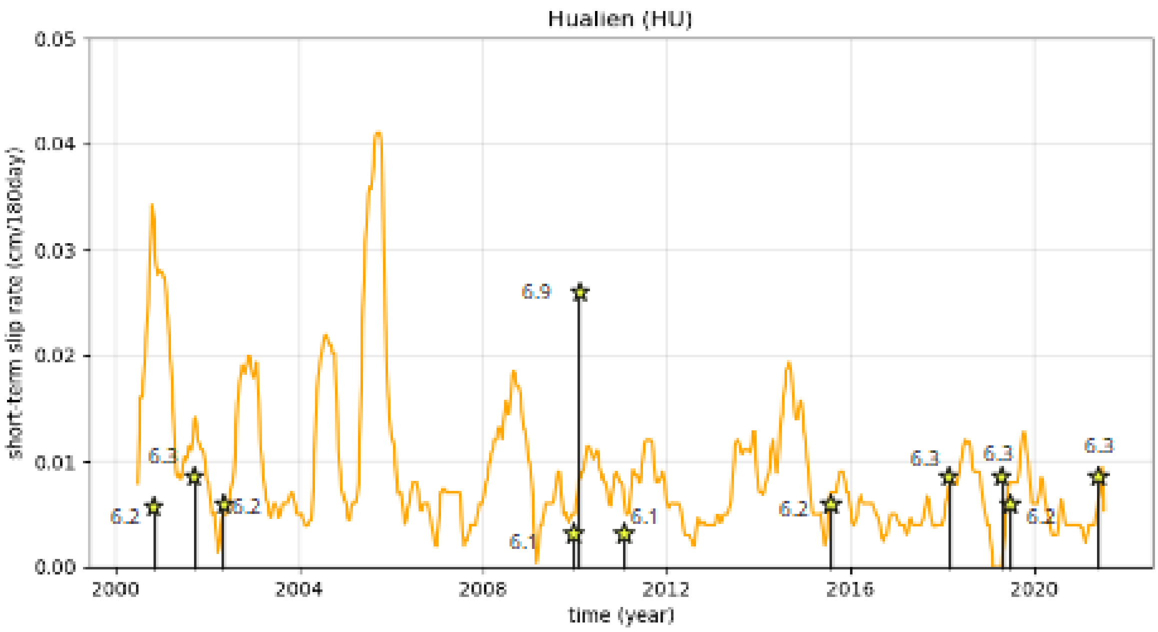

Figure 8. (a) In the Chihshang area, the slip rate increased after the 2006 mainshock and decreased after 2013. (b) In the Hualien area, the slip rate changes from time to time; the relationship between magnitude greater than 6 earthquakes and the slip rate is not obvious.

Conclusion

(a) Using seismic data from 2012-2021, we update the RES catalog from 329 to 447 events, magnitude ranging from ML 2.8 to 4.6.

(b) Most of Tr are shorter than 4 years.

(c) CH: 107 events (16 RES), 23.9%, HU: 252 events (30 RES), 56.4%.

(d) Average slip rate: Chihshang → 2.04 cm/yr, Hualien → 2.15 cm/yr.

(e) The slip in Chihshang was affected by the 2006 earthquake. The slip is stable in Hualien.

(f) The short-term slip rate in Chihshang is significantly lower after 2013, but remains similar in Hualien.

Acknowledgement

We appreciate the Central Weather Bureau and Institute of Earth Sciences for providing earthquake catalog and waveform data.

Reference

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