Spatial and Temporal Distribution of Low Frequency Earthquake Swarm

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1. Introduction

- In studies for earthquake swarms, they usually have characteristics like spatial and temporal migration with time, and low frequency signal in certain area.
- The possibilities of its physical properties could be magma movement, or fluid injection leads to pore-pressure change, let the earthquakes happened.
- In this project, we focus on the earthquake cluster that occur on Hualien in 2021, try to explore their spatiotemporal characteristic, and understand what kind of physical properties controlled the earthquake mechanism.

2. Type of Earthquake Cluster

- Earthquake cluster is a group of earthquakes who occurred very close in space and time.

1. **Mainshock-aftershock sequence:** the largest magnitude shock(mainshock) occurred in the beginning. Aftershocks number decrease exponentially with time.
2. **Swarm sequence:** the mainshock seems occurred later in the sequence. Aftershocks number didn't decay with time.

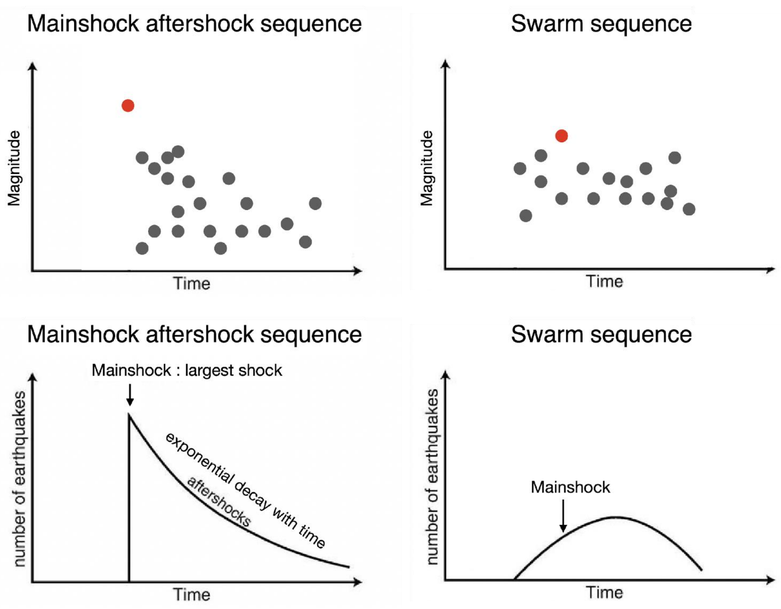


Fig.1 Two types of earthquake cluster divided by temporal characteristic.

3. Characteristics of Earthquake Swarm

- **Spatial Migration is often related to fluid activity:** (Fig.2) This is an example of the largest recorded non-volcano swarm that occurred on the Cahuilla fault in the south California. This figure shows a clear spatial migration from the deeper depth to the shallower depth.
- (Fig.3) Those dash curves represent pore-pressure triggering fronts for the given values of the diffusivity D in the equation on the top. We focus on the earthquakes location with the pore-pressure triggering front, it shows that those earthquakes might be triggered by the pore-pressure change on a fault plane.
  And this diffusivity D is determined to be ranged from 0.02 (zero point zero two) to about 10 m2/s.

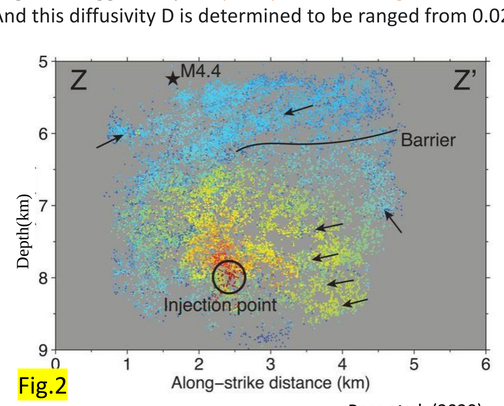


Fig.2 Ross et al. (2020)

$$r = \sqrt{4\pi D t}$$

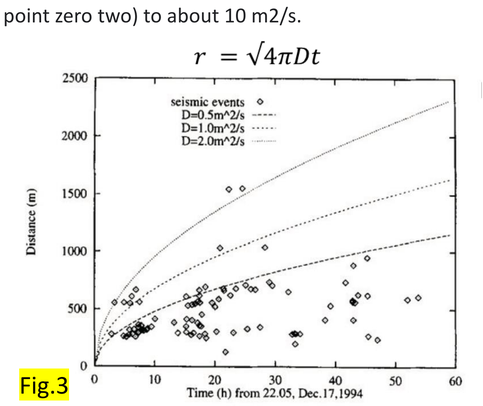


Fig.3 Shapiro et al. (1997)

- **Earthquake swarm has long duration specifically on the lower frequency range:** (Fig.4)Here shows an example of a swarm event.
  The upper figure shows the events waveform and the lower figure show its spectrogram.
  At the spectrogram, which the horizontal axes as the time and the vertical axes as the frequency and the color is coded by the amplitude.
  It is well-studied that those long duration of low frequency is mainly because most of the energy is trapped in the fluid-filled conduit and only a small part can escape and propagate through the solid medium to the seismic station.

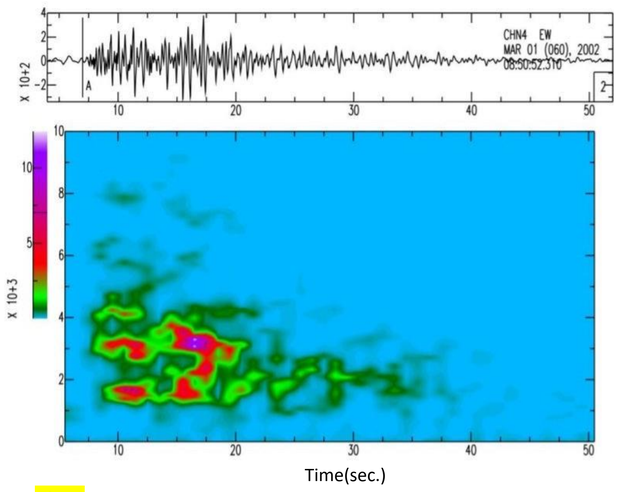


Fig.4 2002/03/01 08:47:45 Spectrogram of station CHN4

4. Hualien Shou-Fong Earthquake Cluster in 2021

- The 2021Hualien 壽豐 earthquake sequence, which is the largest swarm-like sequence occurred on the northern LVF(Longitudinal Valley Fault).
- The sequence starts on 4/18 and ended on 7/18, it shows the spatiotemporal distribution from southwest to northeast which provided by the central weather bureau.
- And if we plot the cross-section, it shows that this sequence occurred on the east-dipping central range fault, and migration from deeper to shallower.

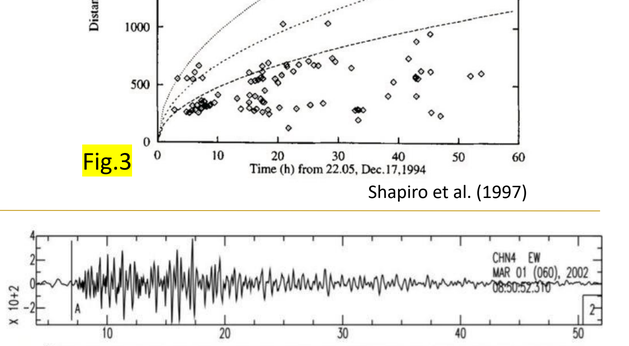
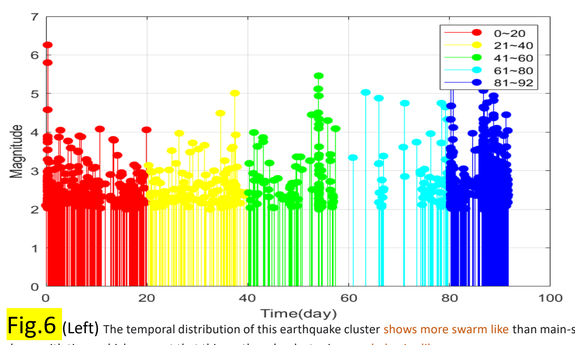


Fig.5



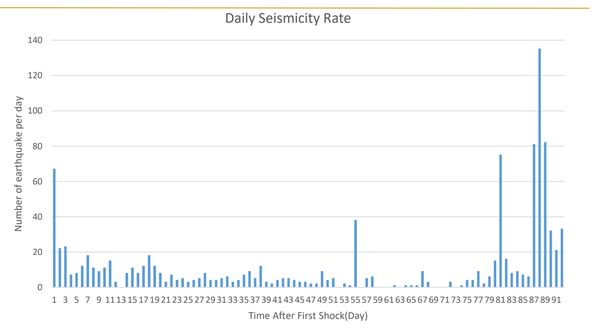


Fig.6 (Left) The temporal distribution of this earthquake cluster shows more swarm like than main-shock-aftershock sequence. (Right) At the daily seismicity rate, you can see that the aftershock's activity didn't decay with time, which suggest that this earthquake cluster is more behavior like a swarm sequence.

5. Analysis Results

5.1 Relocation

- In order to get the earthquake location more precisely to assess the spatial migration, here I use the double-difference location Method (as known as hypoDD) to relocate the relative earthquake location.
- We use the travel time catalog provided by the central weather bureau, 370 M>=2 events were successfully relocated.
- It is clear that the relocated catalog shows more northeast southwest lineation.
- And the cross-section shows a two dip angles fault plane that the dipping angle from 20 degrees at the depth shallower than 10 km up to 50 degrees at the deeper depth.

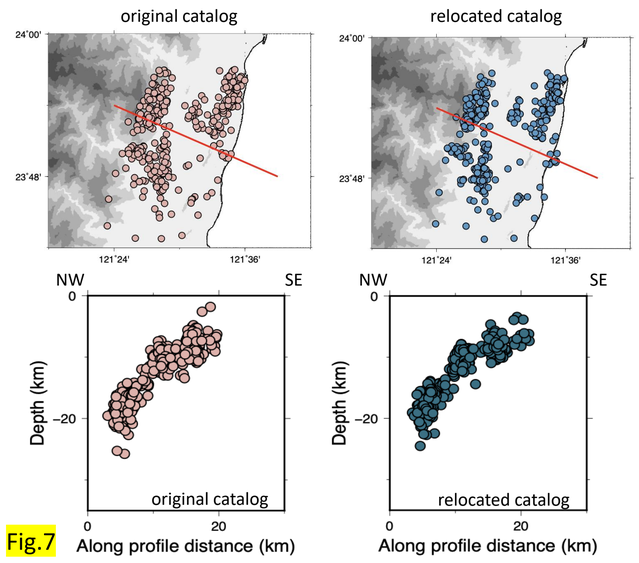


Fig.7

5.2 The migration pattern on the later stage could be modeled as a diffusion process.

- We use this relocated location to calculate the earthquake distance as a function of time, like Fig.8.
- Shows that this earthquake swarm might be driven by the pore pressure change along the fault plane.

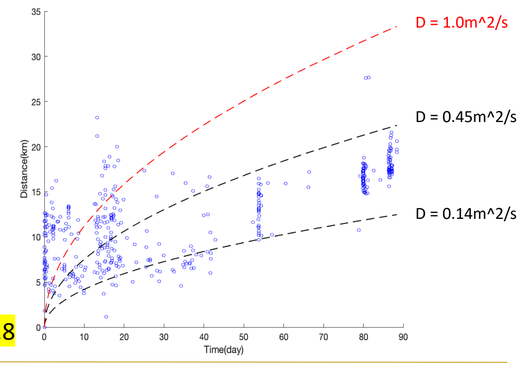


Fig.8

5.3 After analysing 109 magnitude>=3 waveforms at the nearby 6 stations, found that only station EGC shown the low frequency component (Fig.9).

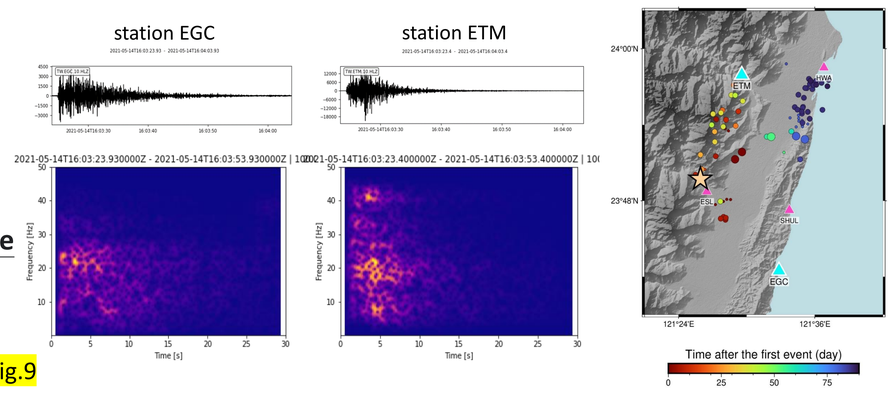


Fig.9

5.4

- In total 109 events, we found 70 events at station EGC shows a significant low frequency component.
- If we simple draw the thee-dimension line between the hypocenter and the station as the direct wave path (Fig.10), it seems that the wave must pass through one specific area to enlarge the low frequency component, so we suspect there must be some fluid in it.

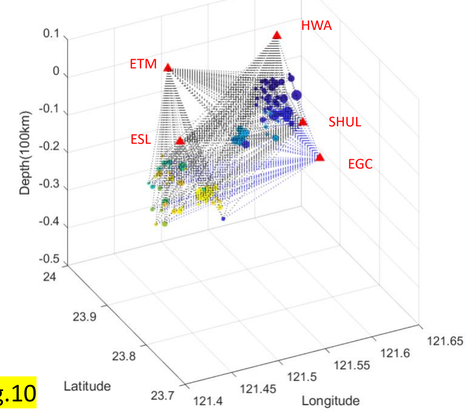


Fig.10

5.5 In order to prove our suspicion, we also look at the vp/vs ratio around then, here we use the vp/vs ratio provided by Huang et al. (2014)
(Fig.11)We make two profiles, profile CC' across the station EGC and profile EE' is from station ETM to station EGC. From the profile CC', there exist **high vp/vs ratio** around the station EGC, and the profile EE' shows that those **high vp/vs ratio gradually disappear from south to north**.
So, according to the tomography map, we know that the fluid might come from this confined area, but what kind of the mechanism controls the fluid flow needs to be carefully investigation in the future.

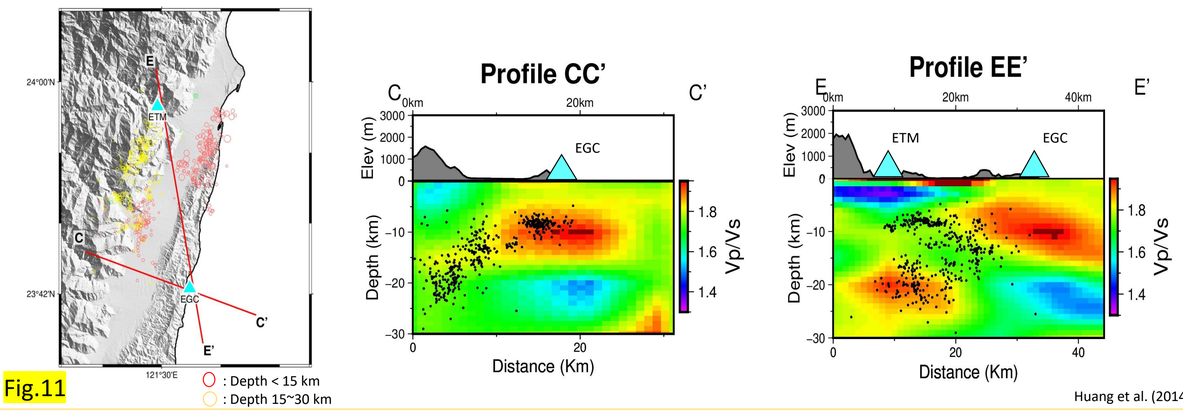


Fig.11 Huang et al. (2014)

6. Summary

- Using the earthquake catalog provided by the Central Weather Bureau, we studied the **2021 Shou-Feng earthquake swarm sequence**, what is the possible mechanism.
- Earthquake relocated using the catalog arrival shows a narrow northeast-southwest trend and the spatiotemporal distribution suggest that **the migration pattern could be triggered by the fluid diffusion process.**
- To locate the source of fluid, we search for low frequency events, in 6 stations and 600 waveforms, **only station EGC recorded 70 low frequency events**, corresponding with **high Vp/Vs** ratio environment.

7. References

The references are in this Google Drive file!
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