Dynamic Analysis of Groundwater Level Anomalies Induced by the 0403 Hualien Earthquake: High Sampling Rate Insights from the Milun Fault Groundwater Observation System

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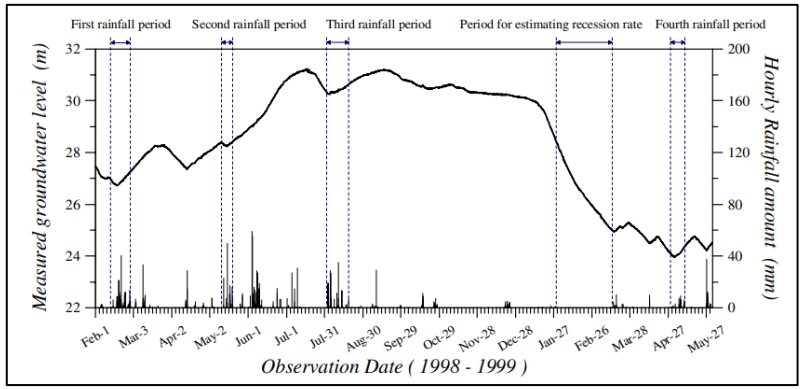
Introduction

Groundwater Level Changes Characteristics

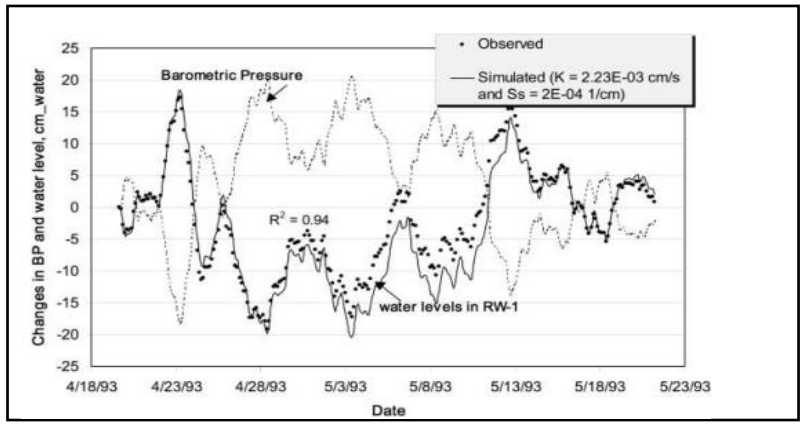
- The groundwater level could be affected by the environmental factor that can trigger a response or called as stimuli.
- The natural stimuli such as earth tide, sea tide, rainfall, barometric pressure and earthquake usually contribute more to the head variations of a groundwater system than does artificial stimuli such as pumping.

Rain



Rainfall as a recharge will lead to do gradually increase to the groundwater level **(Jan et al., 2007)**.

Barometric Pressure

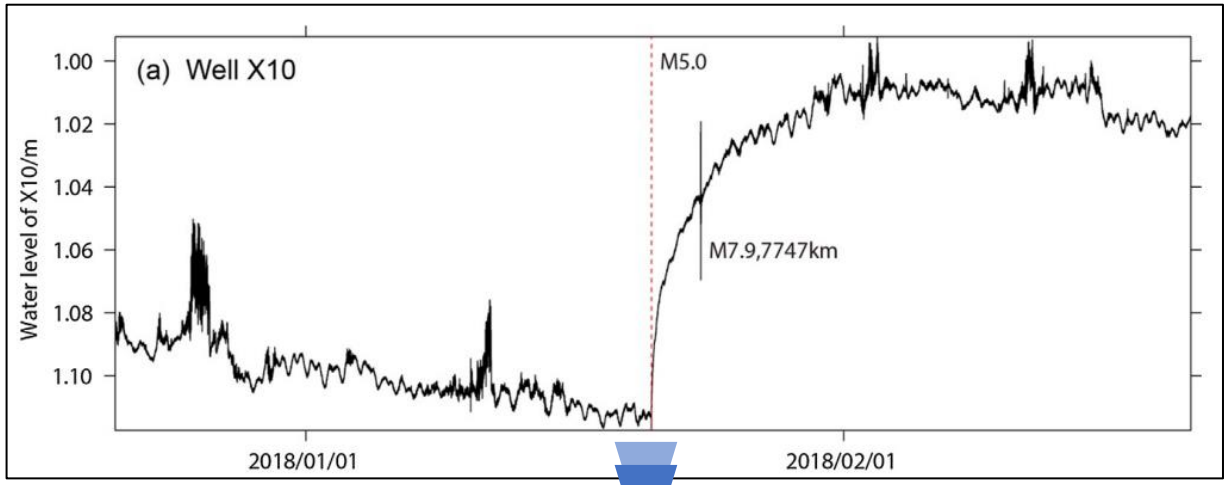


An increase in barometric pressure will cause the groundwater level to show a declining trend **(Seo, 2014)**.

Groundwater Level Changes Related to Earthquake

Groundwater level changes due to the 2018 M 5.0 Urumqi, China earthquake **(Orihara et al., 2014)**.

Earthquake

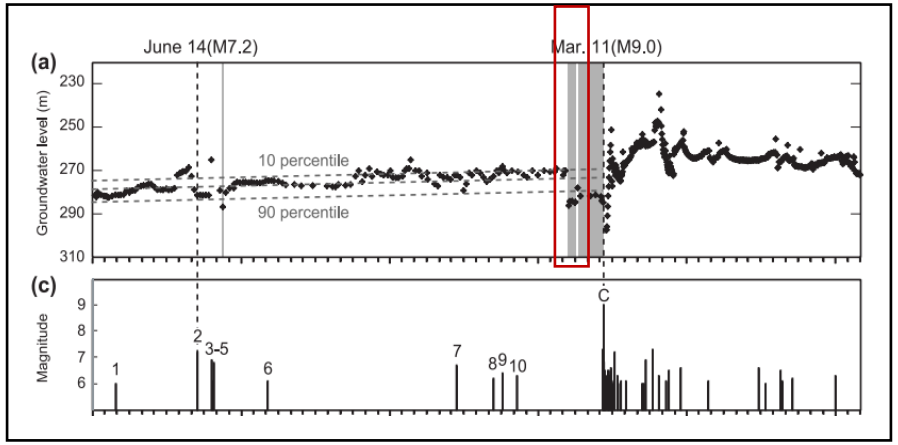


Significant Abrupt Transition

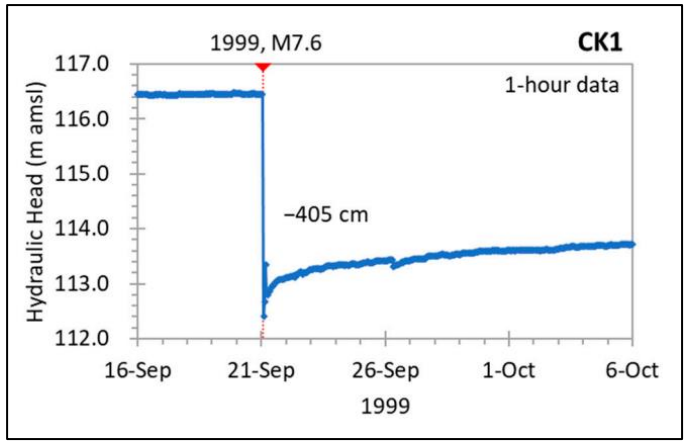
Anomaly

Earthquake Related Groundwater Level Anomaly

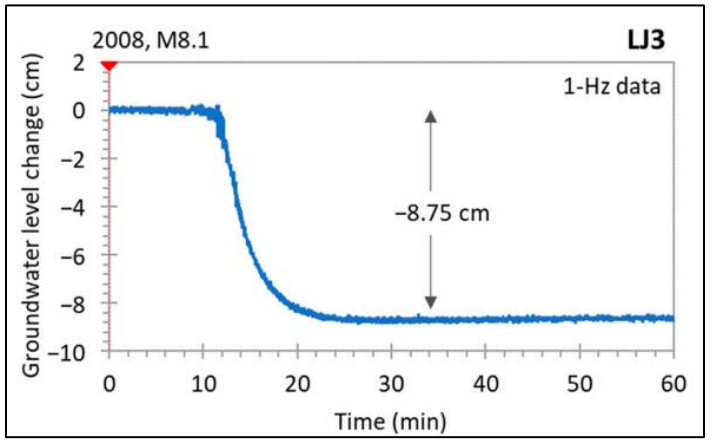
- The fluid in the crust is very sensitive to crust strain and solid deformation lead to the groundwater level changes in a well from the confined aquifer even if the deformation in the crust is small **(Shi et al., 2008)**.
- Earthquake related groundwater anomaly:
  - Pre-seismic (before the earthquake event)
  - Co-seismic (at the earthquake event)
  - Post-seismic (after the earthquake events)



Anomalous groundwater changes started three months before 2011 M 9.0 off the pacific coast of the Tohoku Earthquake, Japan **(Orihara et al., 2014)**.

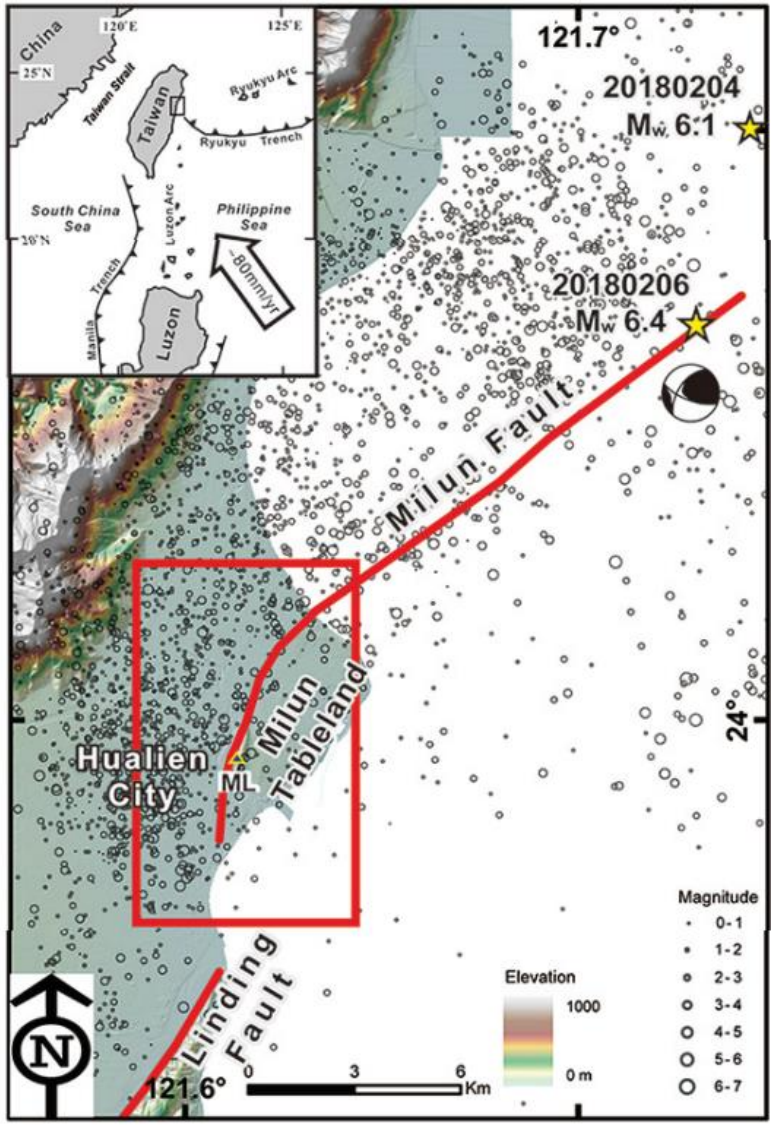


A co-seismic fall due to the 1999 M 7.6 Chi-Chi earthquake **(Liu et al., 2023)**.



Sustained changes recorded following the 2008 M 8.1 Wenchuan earthquake **(Liu et al., 2023)**.

Study Area



(Source: Naik et al., 2022)

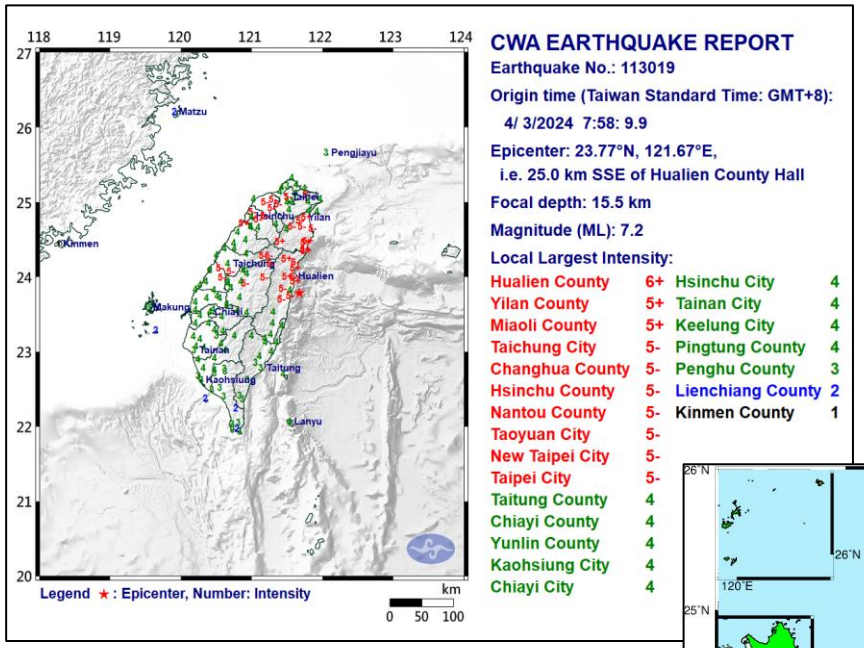
Hualien:

- The region within a 250 km radius around the Hualien, until 2018, has experienced 180 earthquakes of Mw 6.0+, out of which 26 events had a magnitude higher than Mw 7+ .
- The Hualien city has experienced several damaging earthquakes due to the complex tectonic setting and ongoing collision between the Philippines Sea Plate and the Eurasian Plate (**Naik et.al., 2022**).

Milun Fault:

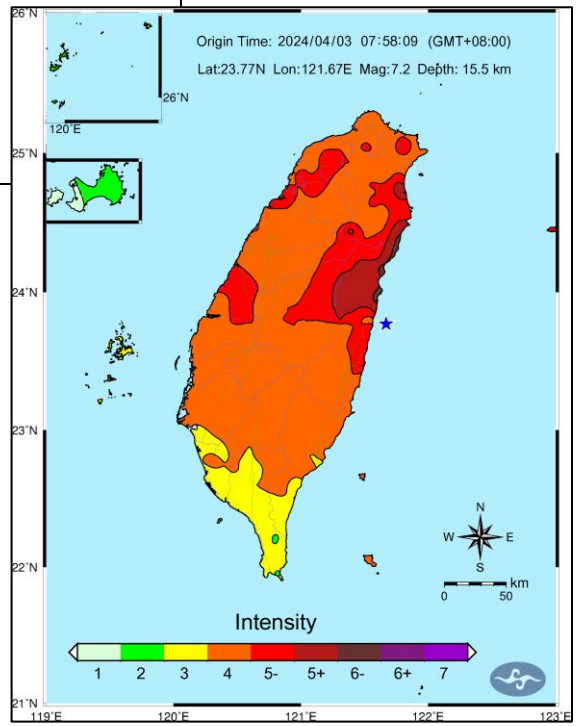
- The continuous convergence rate between the Philippines Sea Plate and the Eurasian Plate is approximately ±80 mm per year.
- Hualien experienced numerous earthquakes due to Milun active tectonic setting.

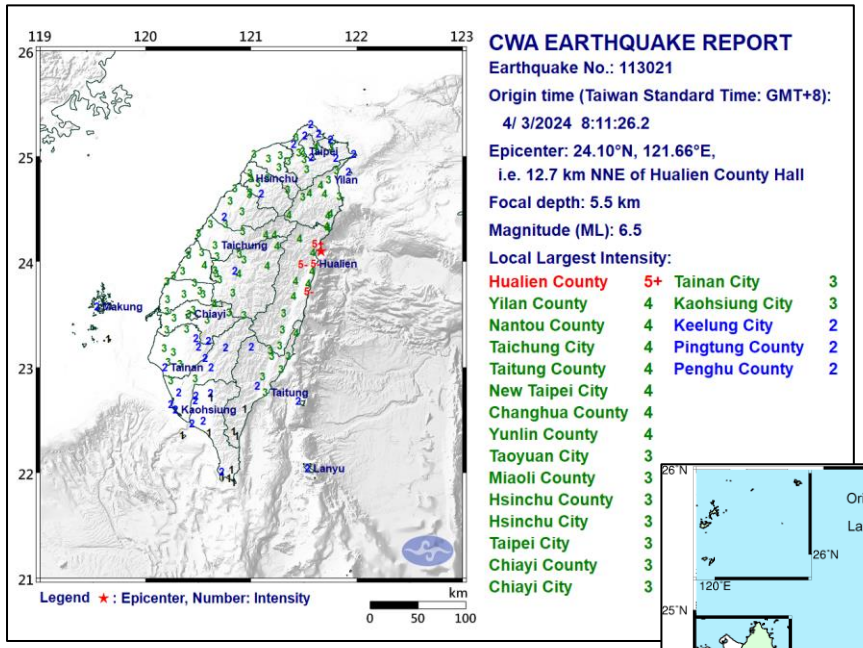
0403 Hualien Earthquake



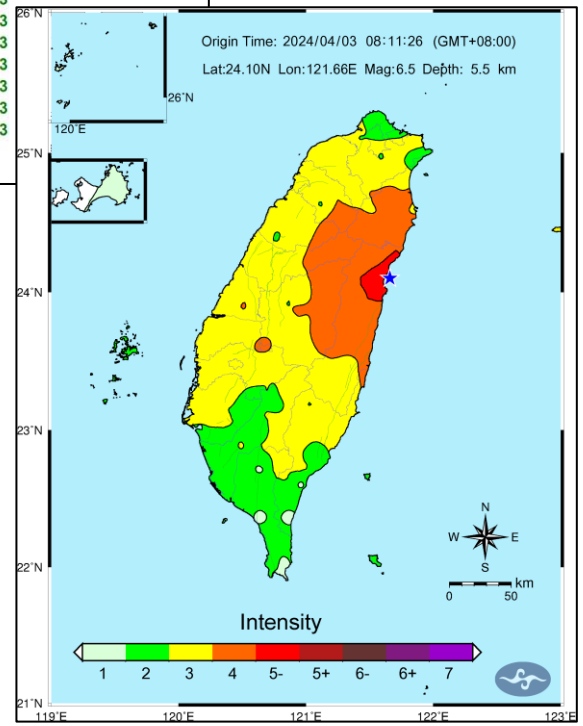
M_L = 7.2 (07.58)

Following by





M_L = 6.5 (08.11)



Objective

Understand the characteristics of fault-fluid interactions and the probability of co-seismic groundwater level changes by analyzing the causes of groundwater level anomalies in the Hualien area during the 0403 Hualien earthquakes, utilizing an integrated groundwater observation system of the Milun Fault.

Methodology

Flow Chart:

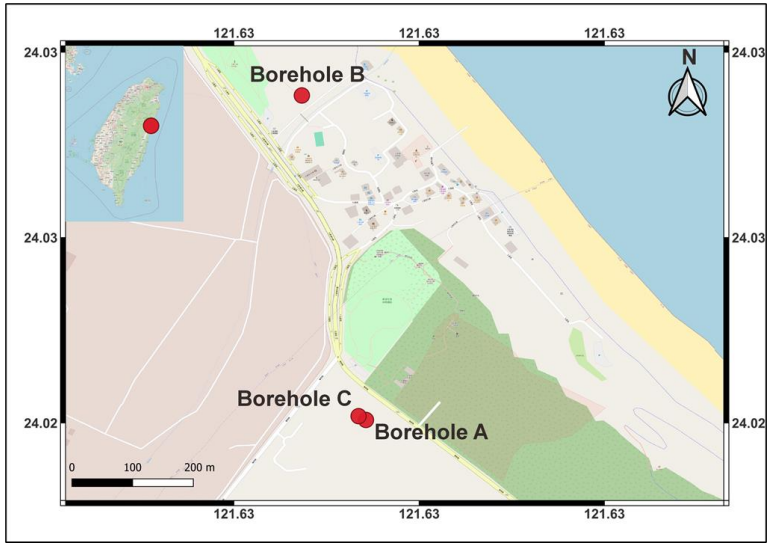
Milun Fault Groundwater Observation System

Sealed System to Decrease Vertical Stimuli	0403 Hualien Earthquake Groundwater Level Anomalies in Different Depth	High Sampling Rate in Groundwater Level Monitoring System
Data: groundwater level, rainfall and barometric pressure	Data: groundwater level readings at various depths	Data: Groundwater level fluctuation in different sampling rate.
Analyze the influence of rainfall and barometric pressure on groundwater levels	Identify and analyze anomalies due to the M 7.2 and M 6.5 Hualien Earthquakes	Compare and evaluate how different sampling rates capture groundwater level fluctuations
Assess the sealed system's effectiveness in reducing vertical stimuli	Examine the amplitude of groundwater level anomalies in response to seismic events	Examine how higher sampling rates capture dynamic groundwater level changes

New System for Pressure Monitoring Well

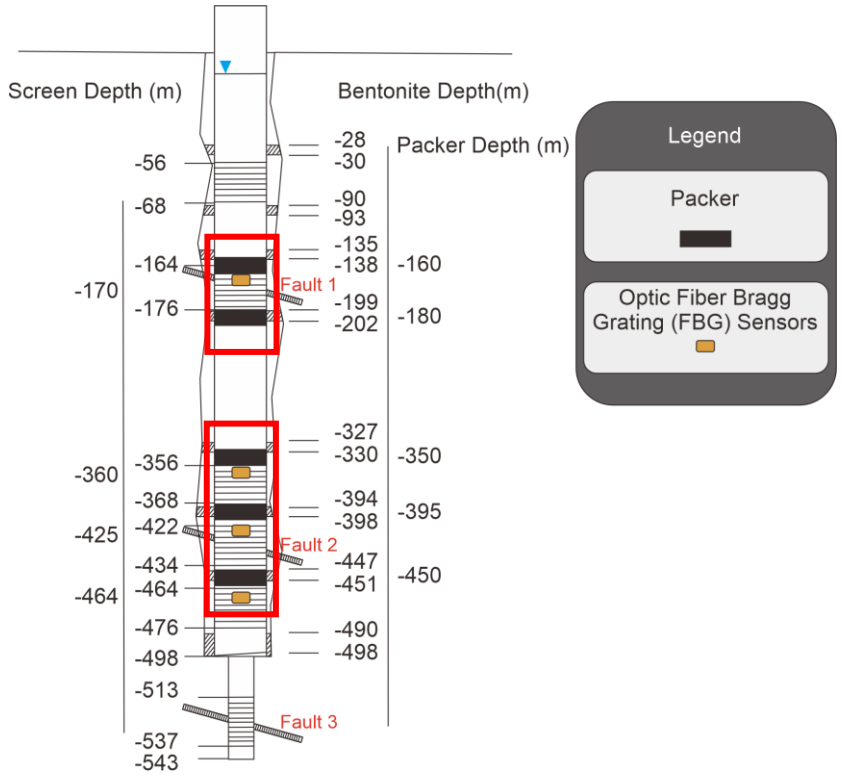
The Integrated Groundwater Observation System of Milun Fault

Data Sources:



Data	Sources
Groundwater Level	Borehole C
Barometric Pressure	Borehole C
Rainfall	Borehole C
Seismic	Borehole A

Borehole C:



The detail of the system:

- Screen opening is follow the aquifer system
- Packers in each screen
- Water pressure gauge in each screen opening with 200 Hz sampling rate

Water Pressure Sensor:

- -170 m
- -360 m
- -424 m
- -464 m

What's new?

Sealed System → Decrease vertical groundwater level changes stimuli (causes)

High Sampling Rate → Increase the analysis of dynamic groundwater level changes

Data Analysis and Discussion

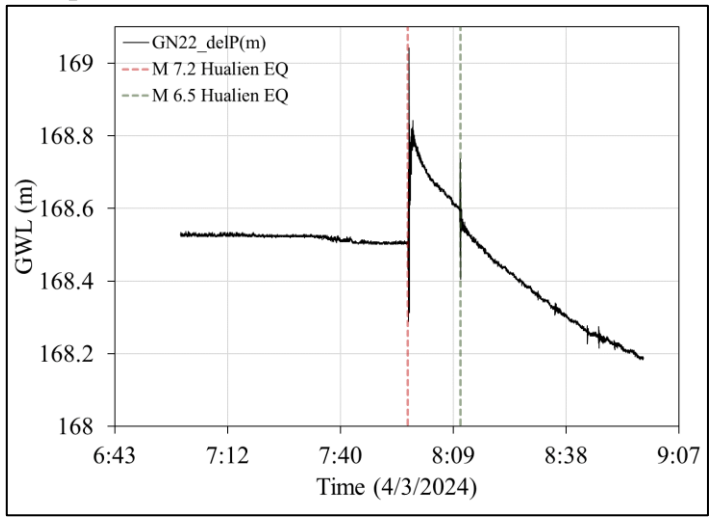
- 0403 Hualien Earthquake Groundwater Level Anomalies in Different Depth
- High Sampling Rate in Groundwater Level Monitoring System

0403 Hualien Earthquake Groundwater Level Anomalies in Different Depth

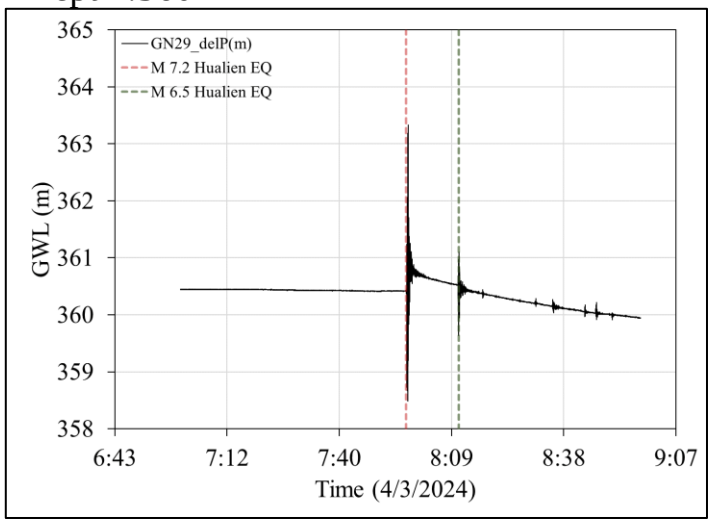
Time: April 3th 2024 (Earthquake Events)

Milun Integrated Groundwater Observation System (Borehole C)

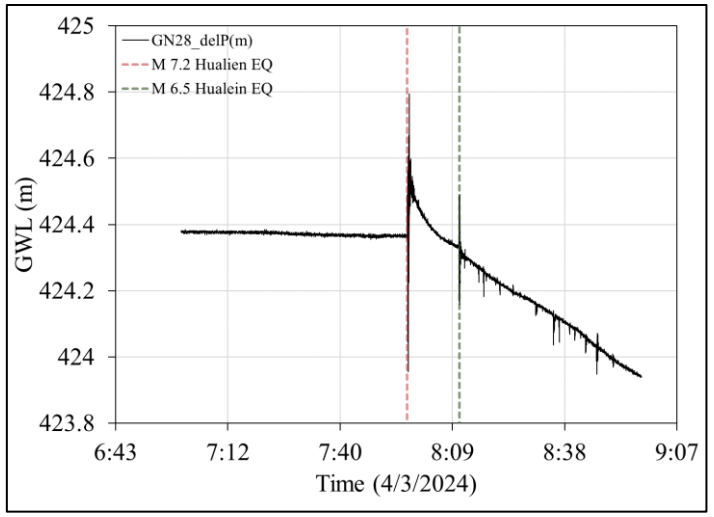
Depth :170 m



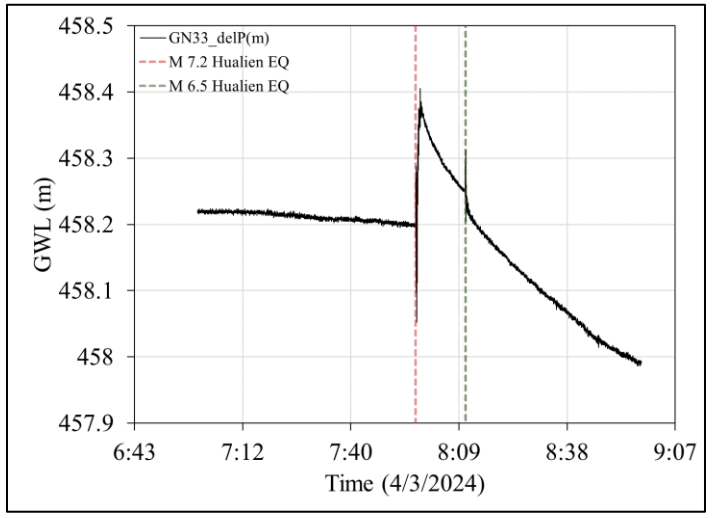
Depth :360 m



Depth :424 m



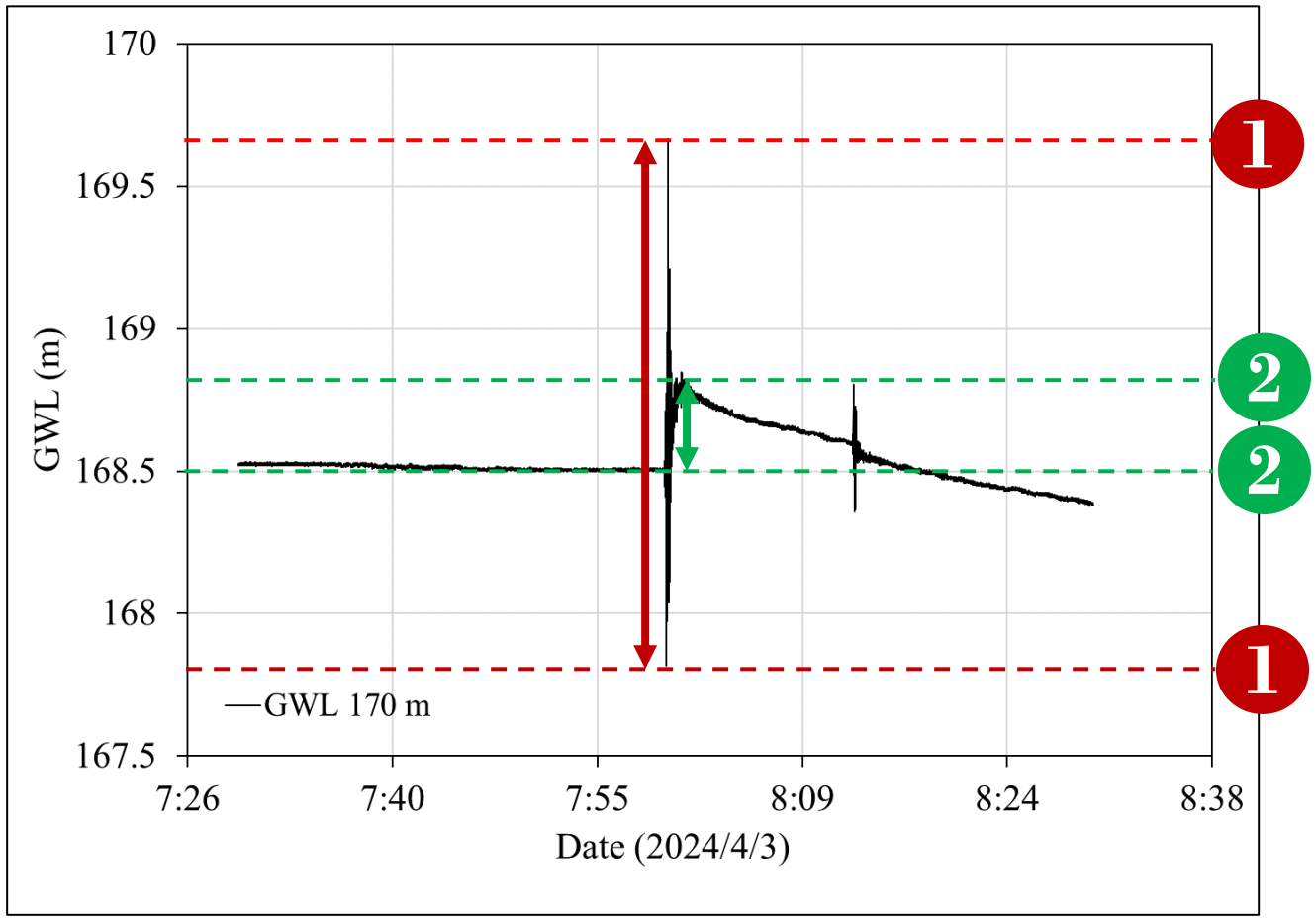
Depth :464 m



Depth (m)	Amplitude of Anomalies (m)	
	M 7.2	M 6.5
170	1.849	0.444
360	9.177	2.543
424	2.647	1.472
464	0.650	0.148

Amplitude of Groundwater Level Changes

Depth :170 m

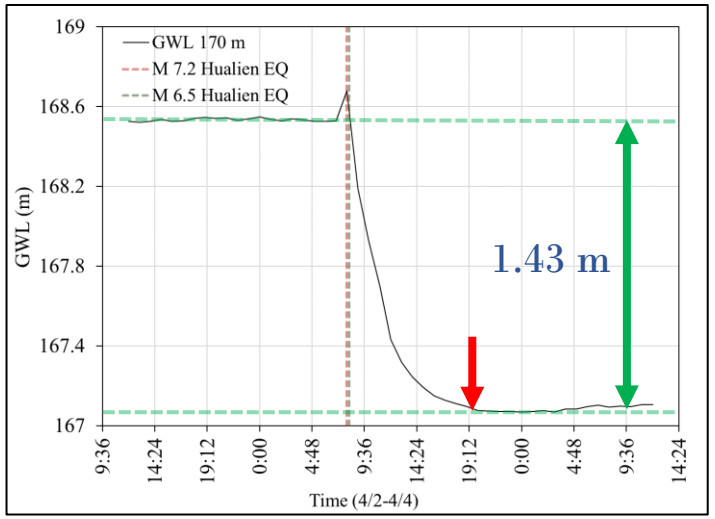


There are two different changes **oscillatory** and **step changes**.

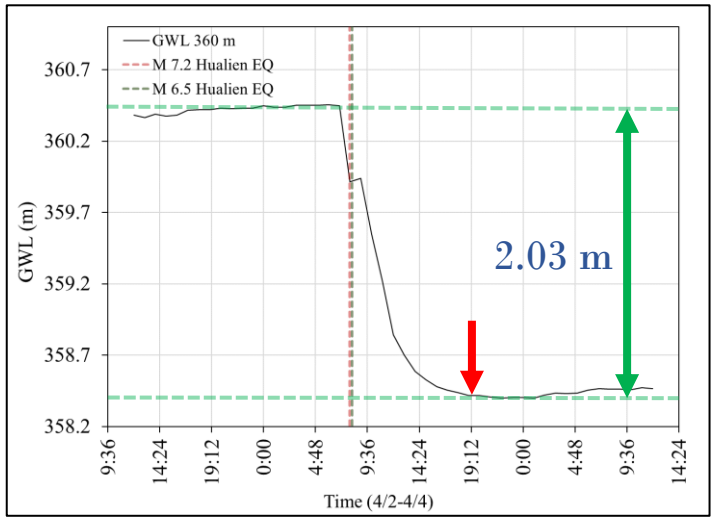
Depth (m)	Amplitude of Anomalies (m)			
	M 7.2 Oscillatory Changes	M 7.2 Step Changes	M 6.5 Oscillatory Changes	M 6.5 Step Changes
170	1.849	0.272	0.444	-0.050
360	9.177	0.380	2.543	-0.124
424	2.647	0.133	1.472	-0.024
464	0.650	0.166	0.148	-0.030

Groundwater Level in 48 Hours

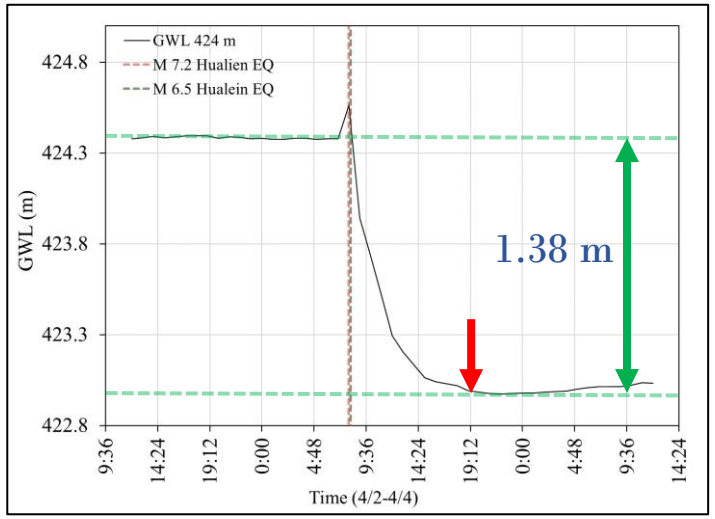
Depth :170 m



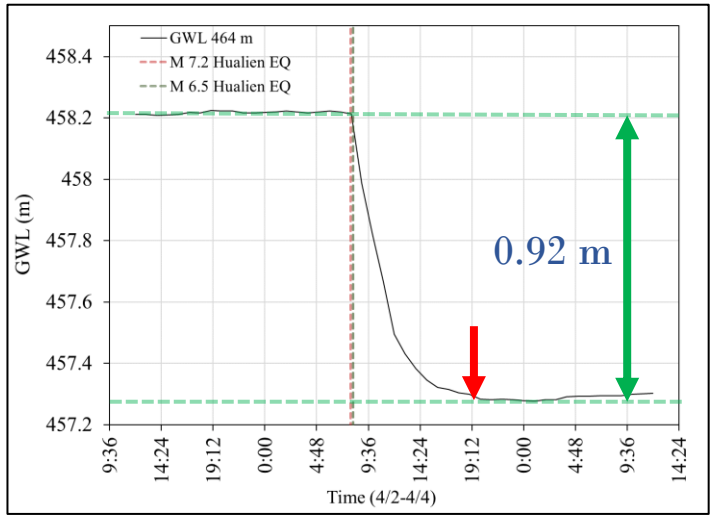
Depth :360 m



Depth :424 m

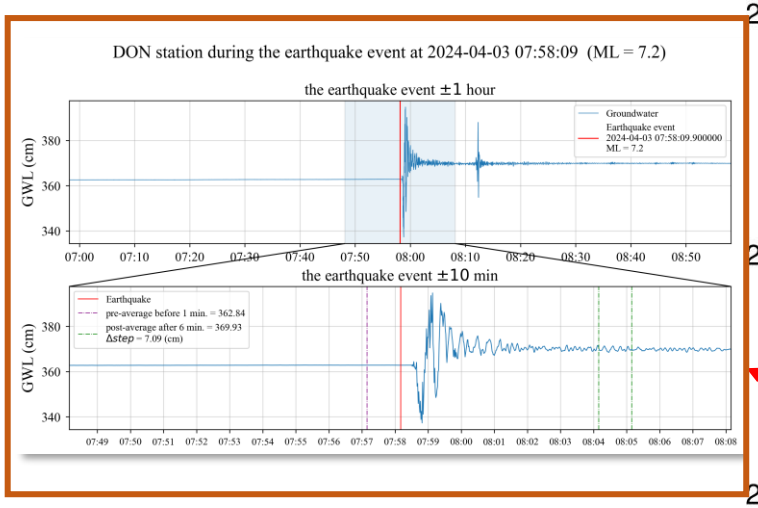


Depth :464 m

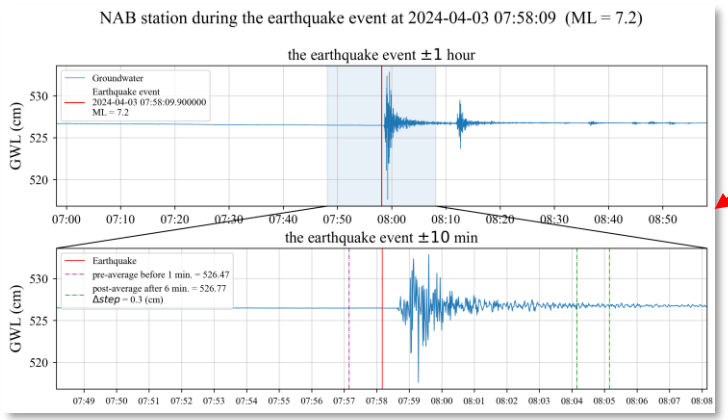


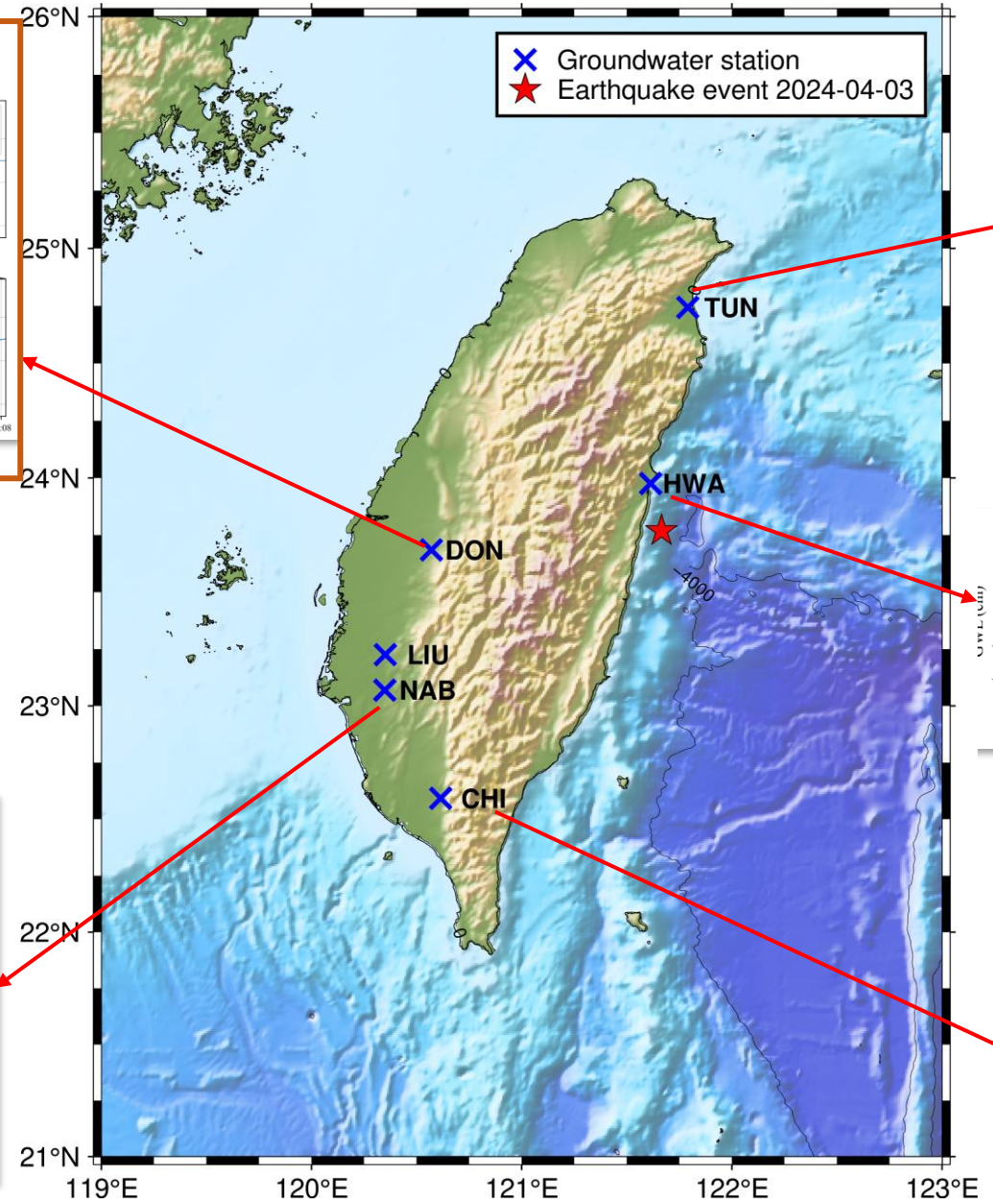
- The data was plotted hourly in two days duration.
- The groundwater level stable after 19:12 (4/3) which is the groundwater level need 11 hours 14 minutes to stable.

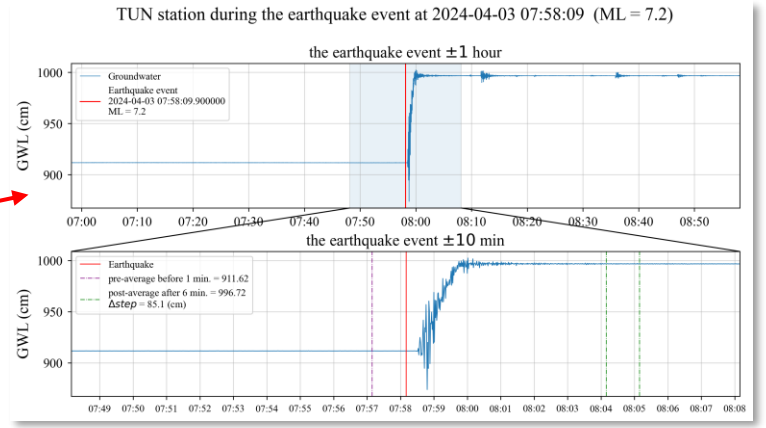
High Sampling Rate in Groundwater Level Monitoring System

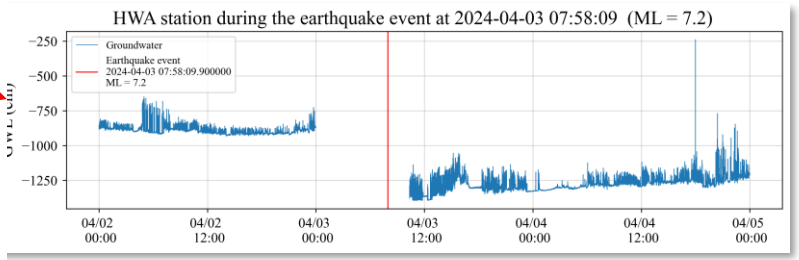


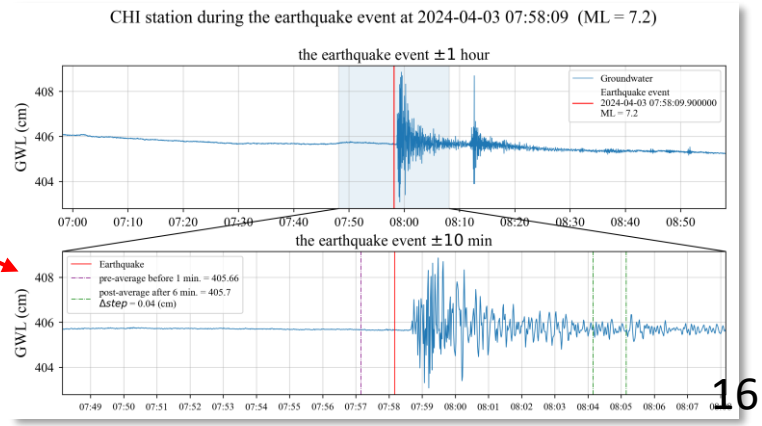
LIU
No data





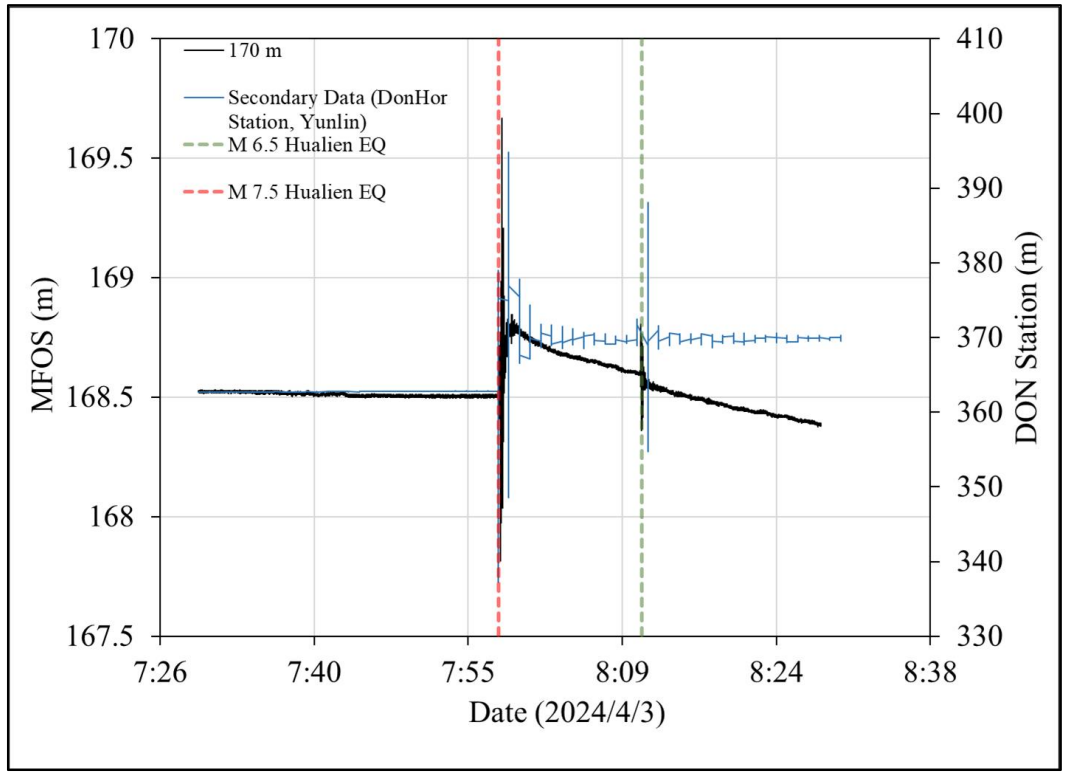






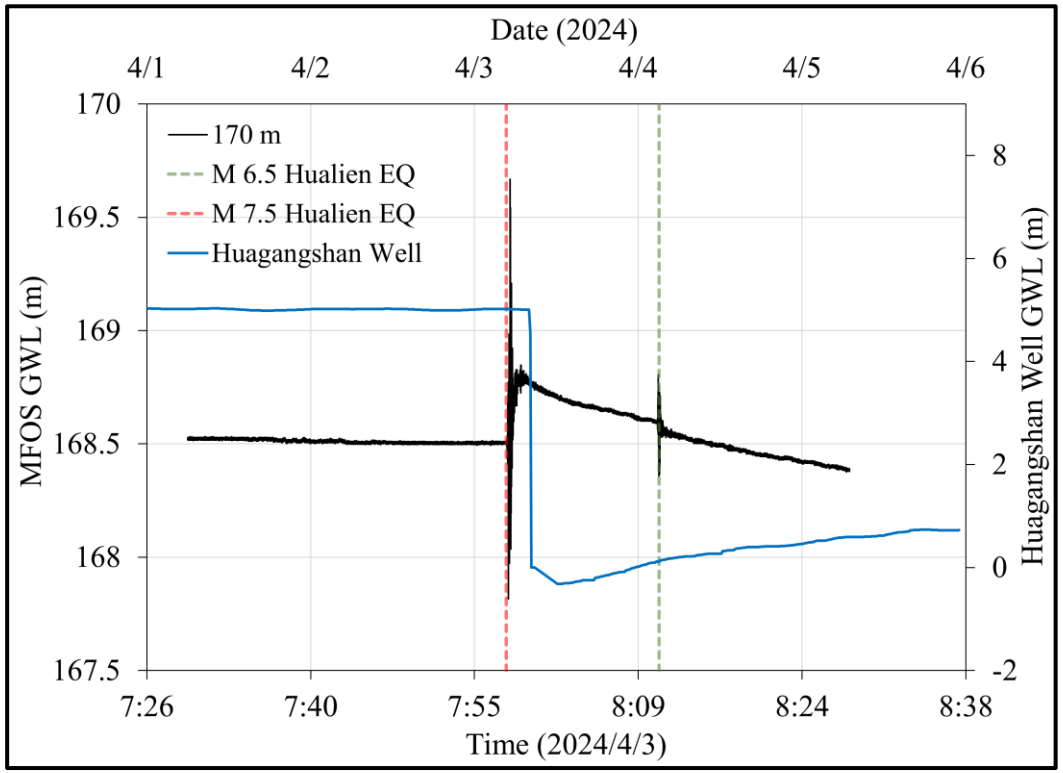
Groundwater Level Anomalies in Different Sampling Rate

200 Hz and 1 Hz Data



DON: Don-Her Station, Yunlin obtained from Taiwan Seismological and Geophysical Data Management System.

200 Hz and 10 minutes

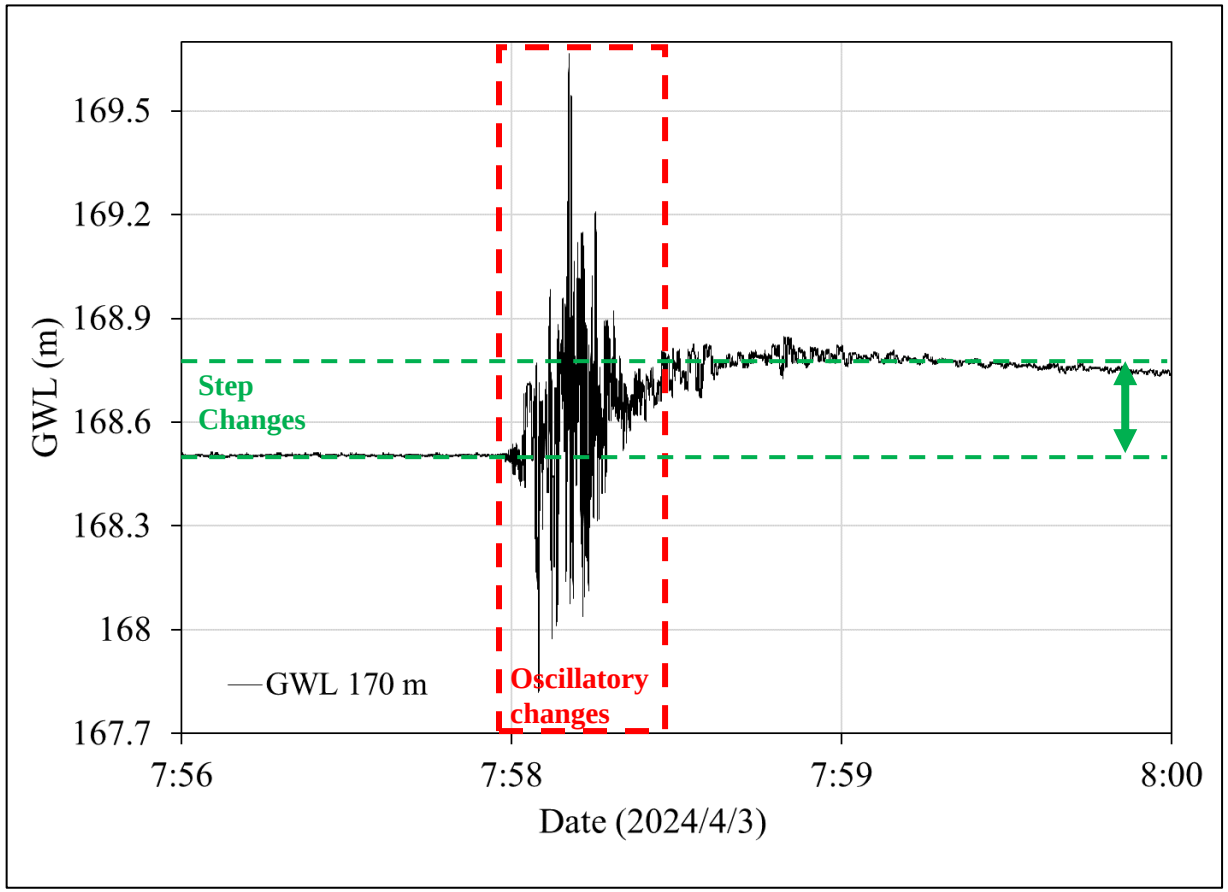


MFOS: Milun Fault Observation System (200 Hz data)

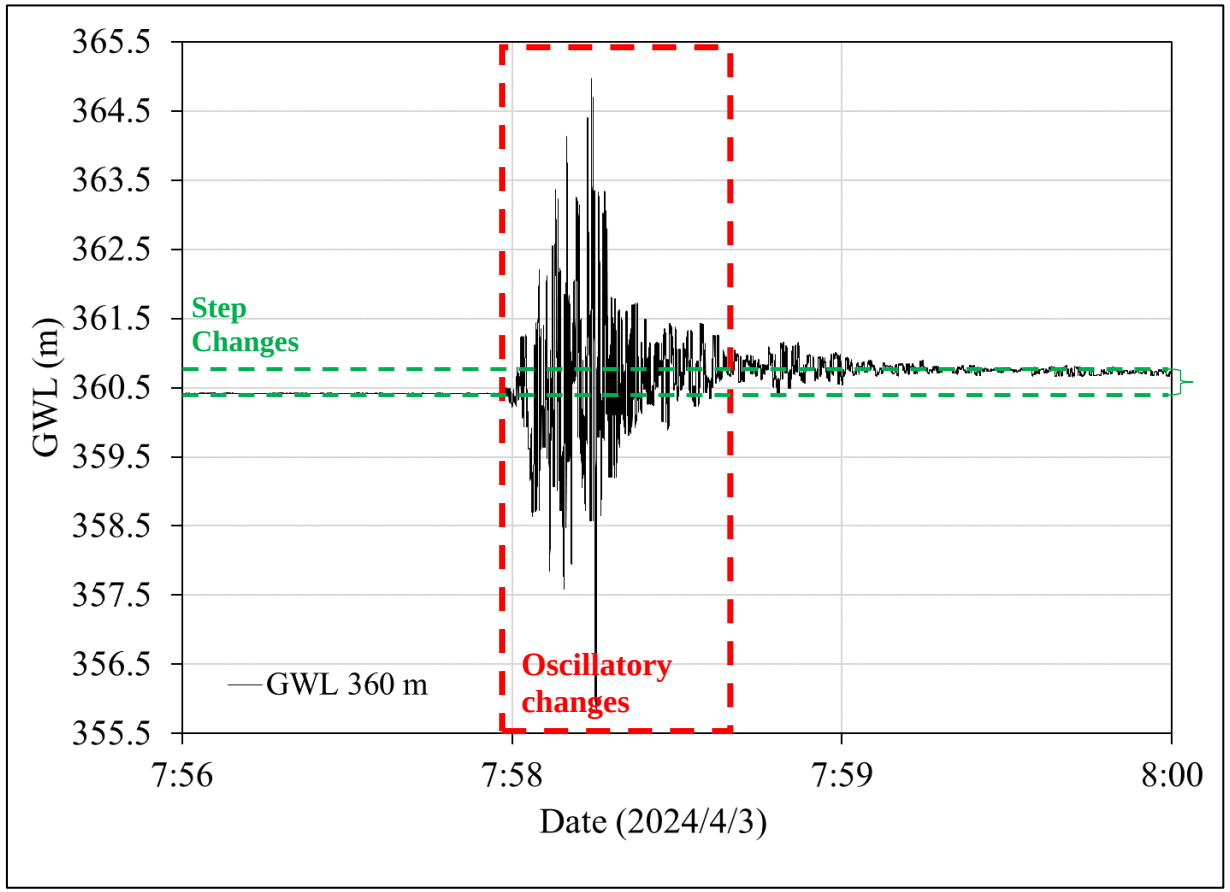
Huagangshan well: Data obtained from Water Resource Agency (10 s sampling rate data)

Groundwater Level Changes in 200 Hz Sampling Rate

Depth :170 m



Depth :360 m



High sampling rate data could record two type of the co-seismic response; oscillation and step changes.

Conclusions

Groundwater Level Anomaly Analysis:

The integrated groundwater observation system of Milun faults able to record the groundwater level co-seismic anomalies due to 0403 Hualien earthquake events. The amplitude of anomaly consistent with the magnitude. The high amplitude recorded in the high magnitude, while the low amplitude recorded in the low magnitude. The groundwater level continue decrease after the earthquake events and stable after ~19.12 (4/3).

High Sampling Rate Effect:

The higher sampling rate data could record more dynamic data and two type of the co-seismic response; oscillation and step changes.

Thank you