Estimation of Groundwater Pumping Using Various Monitoring Data in the Choushui River Alluvial Fan

Seminar – **literatures integration** and **theoretical framework**

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Date ：2025/05/09

Outline

- Introduction
- Methodology
- Results and Discussion
- Conclusions
- Research Directions

In this talk...

Building a research framework to estimate groundwater pumping using various monitoring data (GNSS, MLCW, GW) and poroelasticity theory.

Spatio-temporal estimation of monthly groundwater levels from GPS-based land deformation

Ali, M. Z., Chu, H., Tatas, N., & Burbey, T. J. (2021).

Environmental Modelling & Software, 143, 105123.

Analysis and prediction of land subsidence along significant linear engineering

Ding, P., Jia, C., Di, S., Wang, L., Bian, C., & Yang, X. (2020).

Bulletin of Engineering Geology and the Environment, 79(10), 5125–5139.

Can GNSS displacement help estimate groundwater extraction?

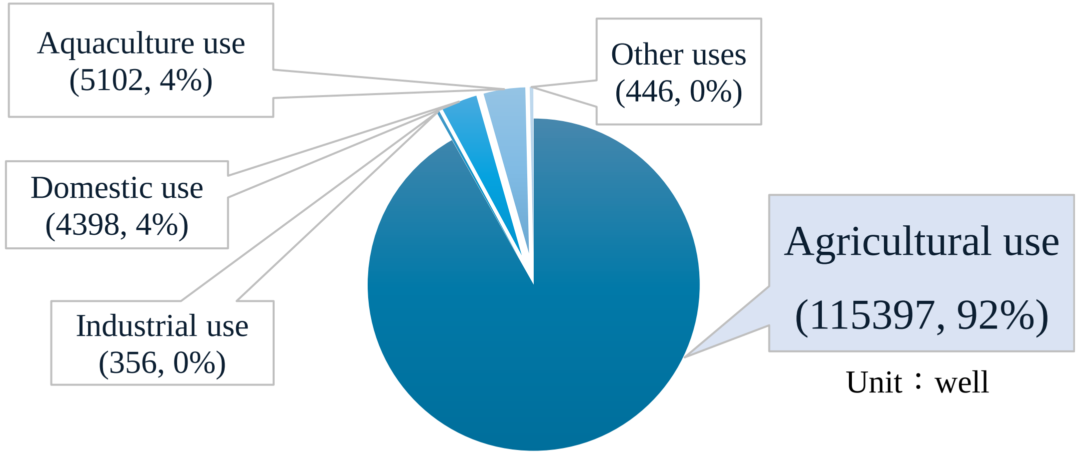
How to develop a deformation model based on poroelasticity?

Behavior description

Layer weighting

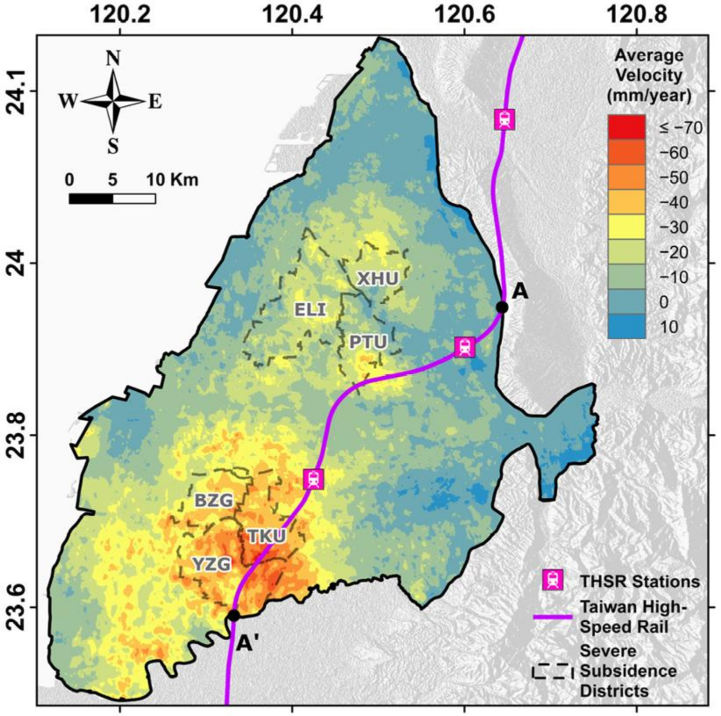
Subsidence prediction

➢ Background



Unit：well

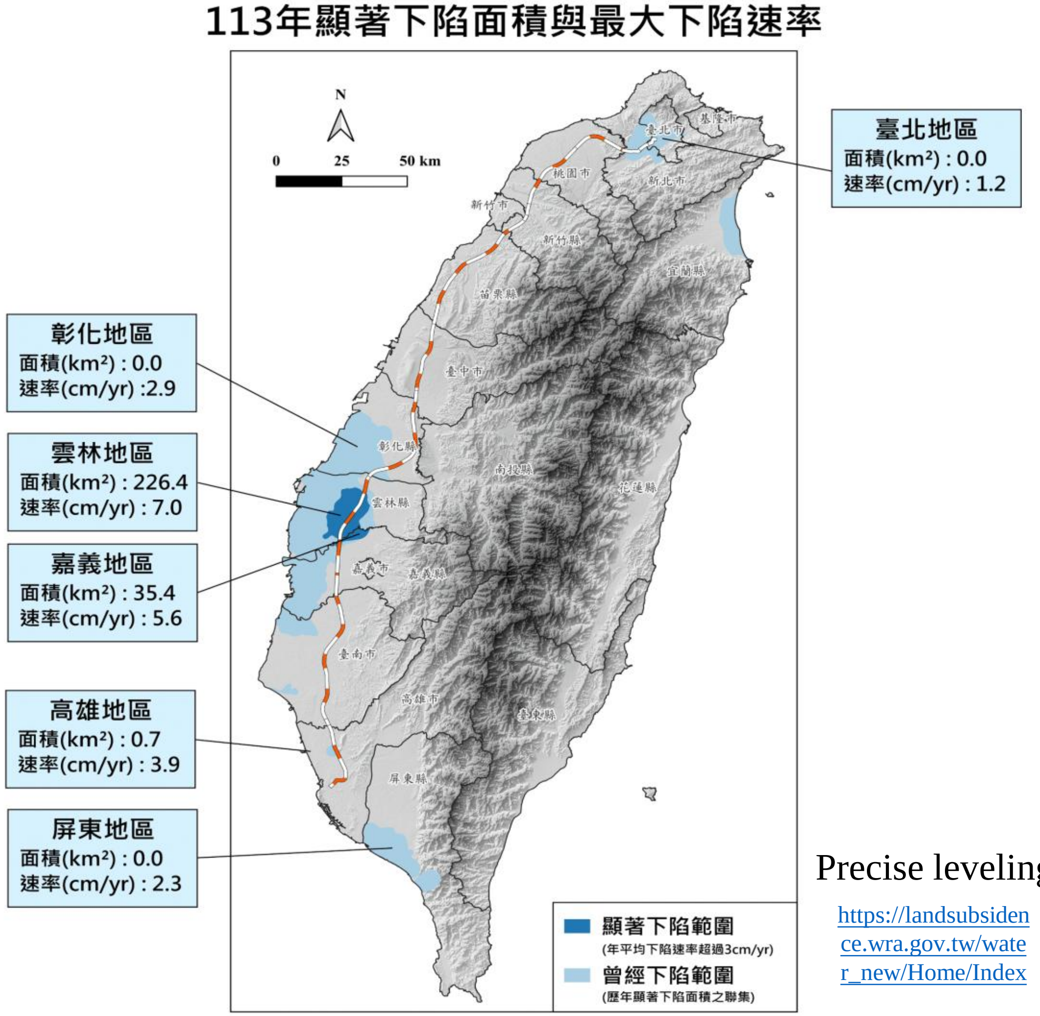
(Hsu et al., 2018)



InSAR-derived average velocities (Nguyen et al., 2024)

April 2016 – October 2022	
Tuku	3.5 cm/year
Yuanzhang	6.7 cm/year
Some areas are over 7 cm/year	

- Significant subsidence (> 3cm/year) → 262.5 km^2

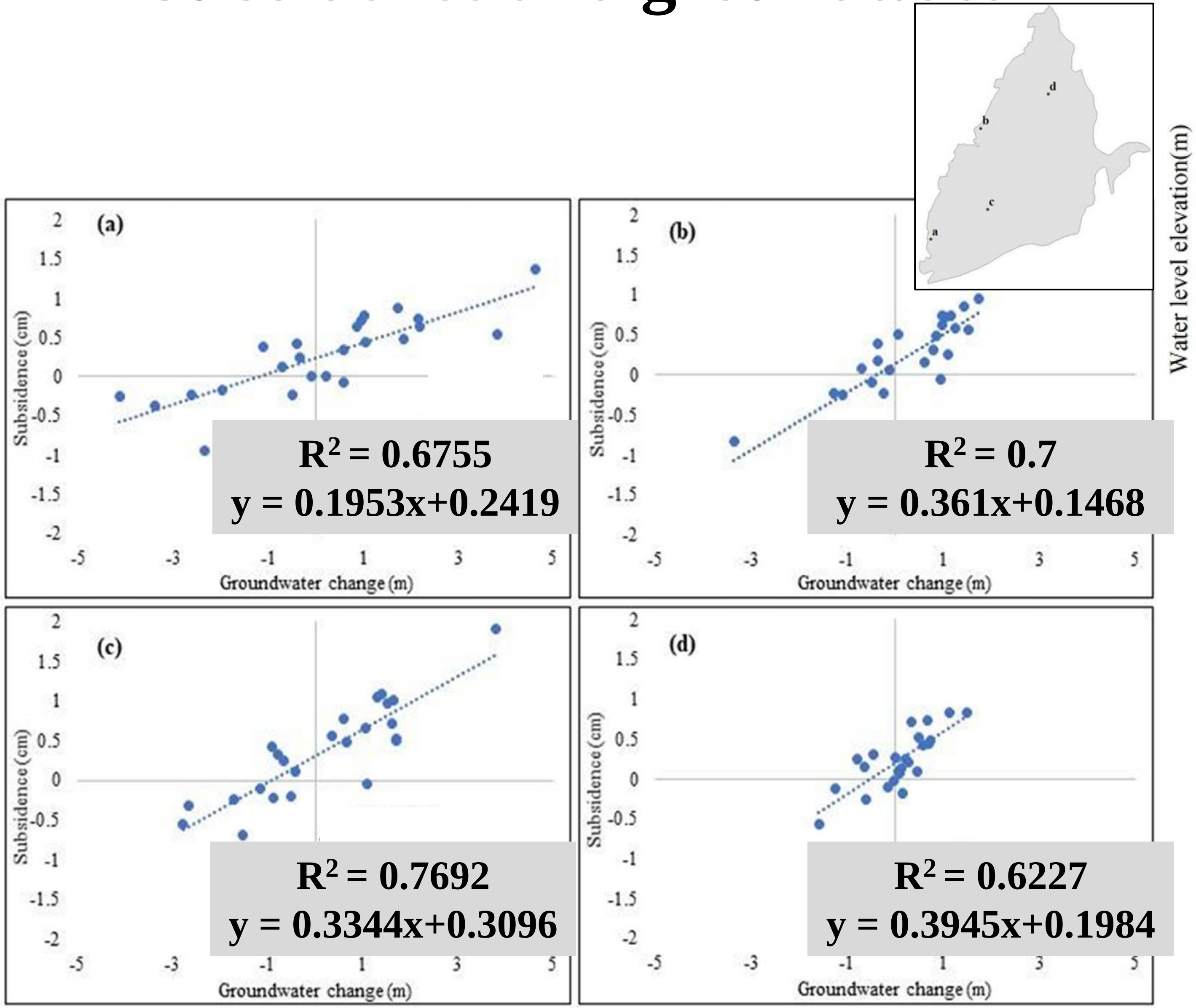


Precise leveling

https://landsubsidence.wra.gov.tw/water_new/Home/Index

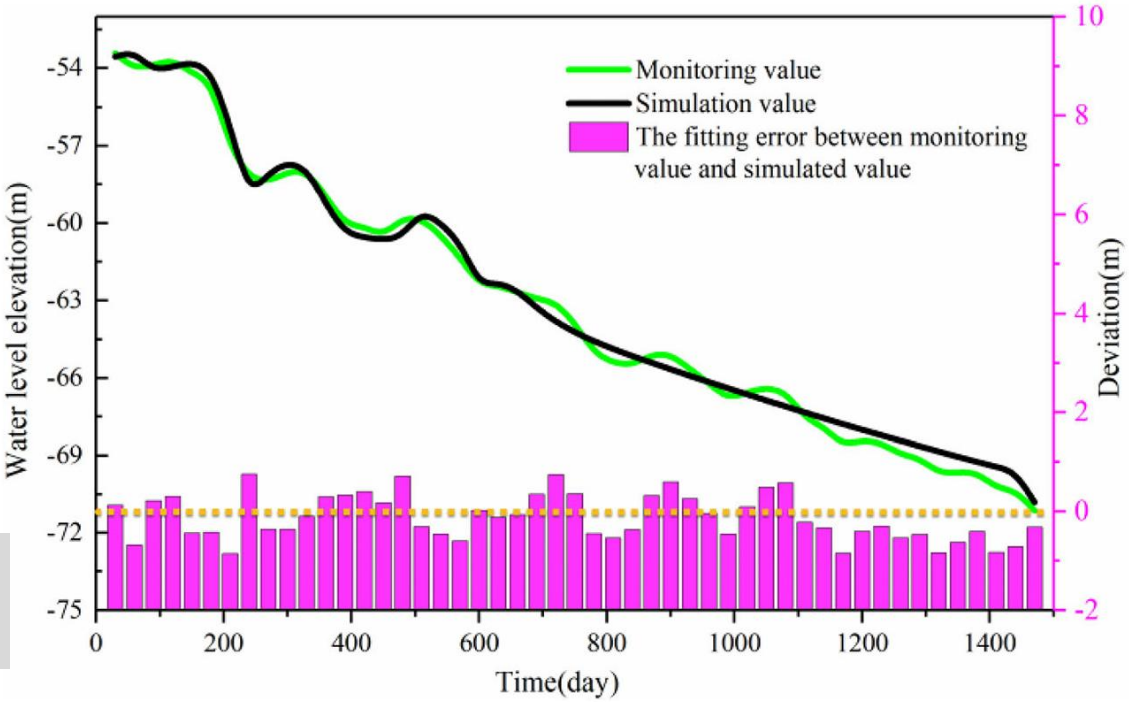
補充說明：本系統內各縣市「最大下陷速率」為該縣市內小區域年最大值，非指全縣市下陷速率。

➢ Subsidence and groundwater



(Ali et al., 2021)

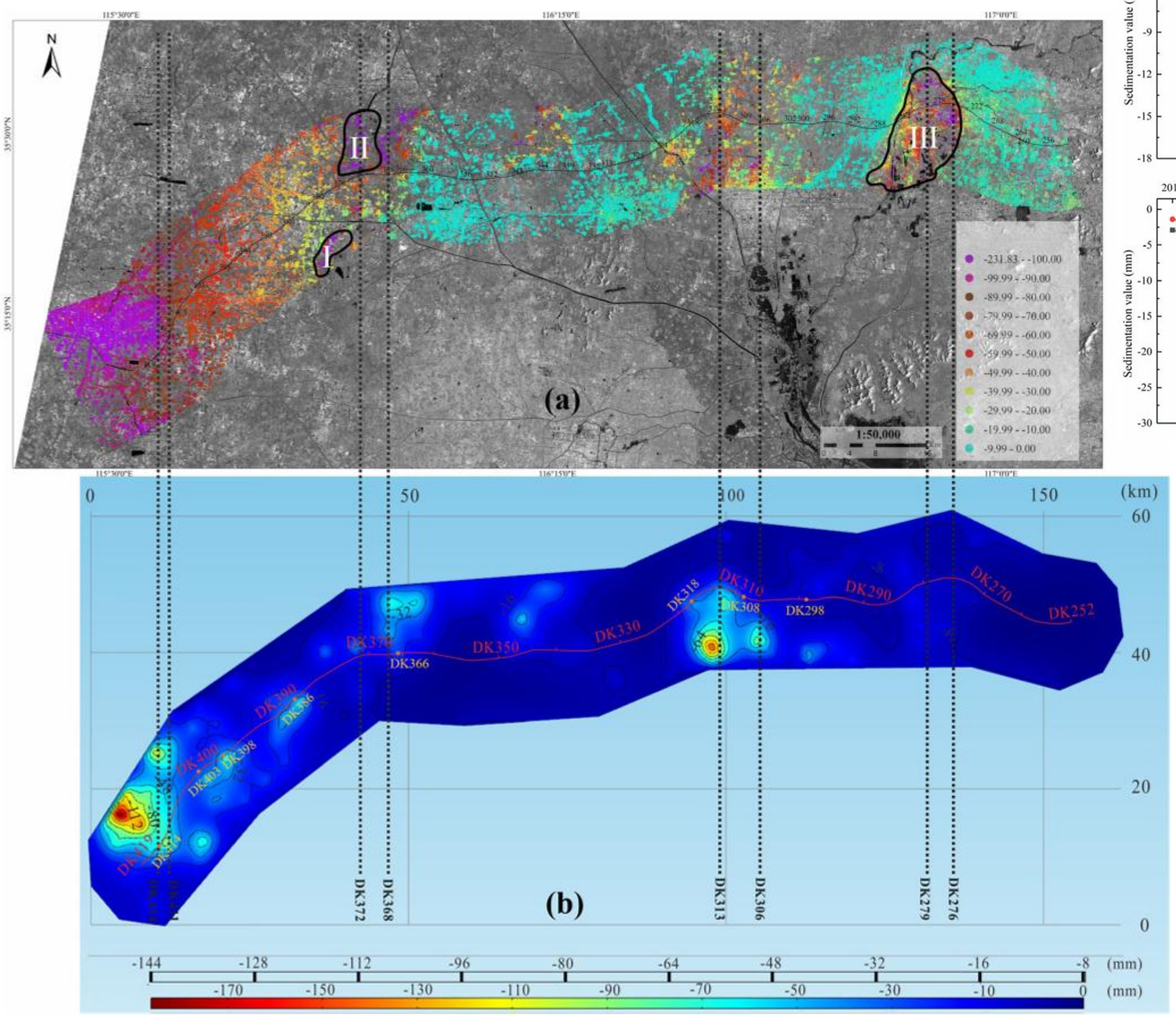
(Ding et al., 2020)



- R^2 values range from **0.62 to 0.77**.
- Slope represents aquifer system compressibility.

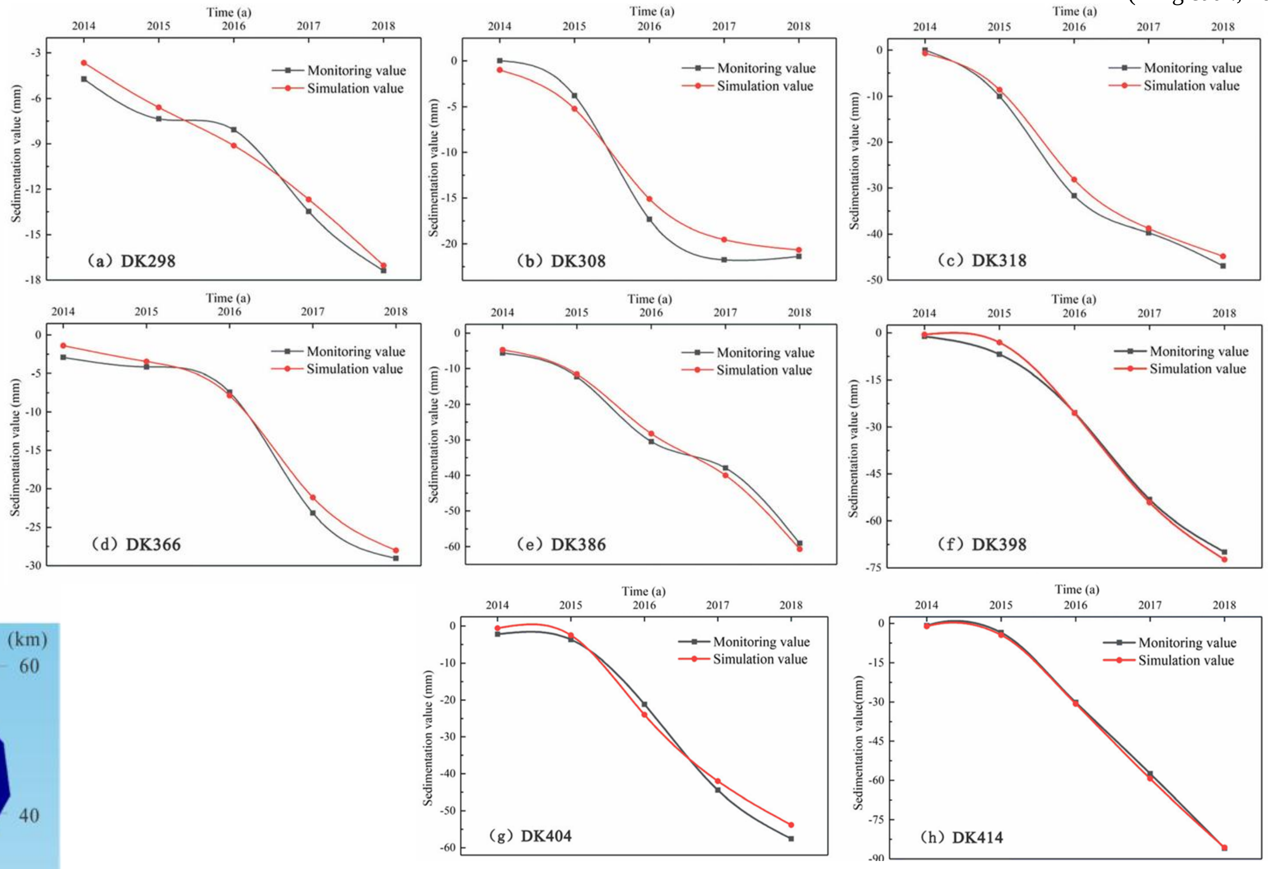
GNSS displacement has potential for estimating groundwater changes.

➢ Spatiotemporal distribution



(Ding et al., 2020)

(Ding et al., 2020)

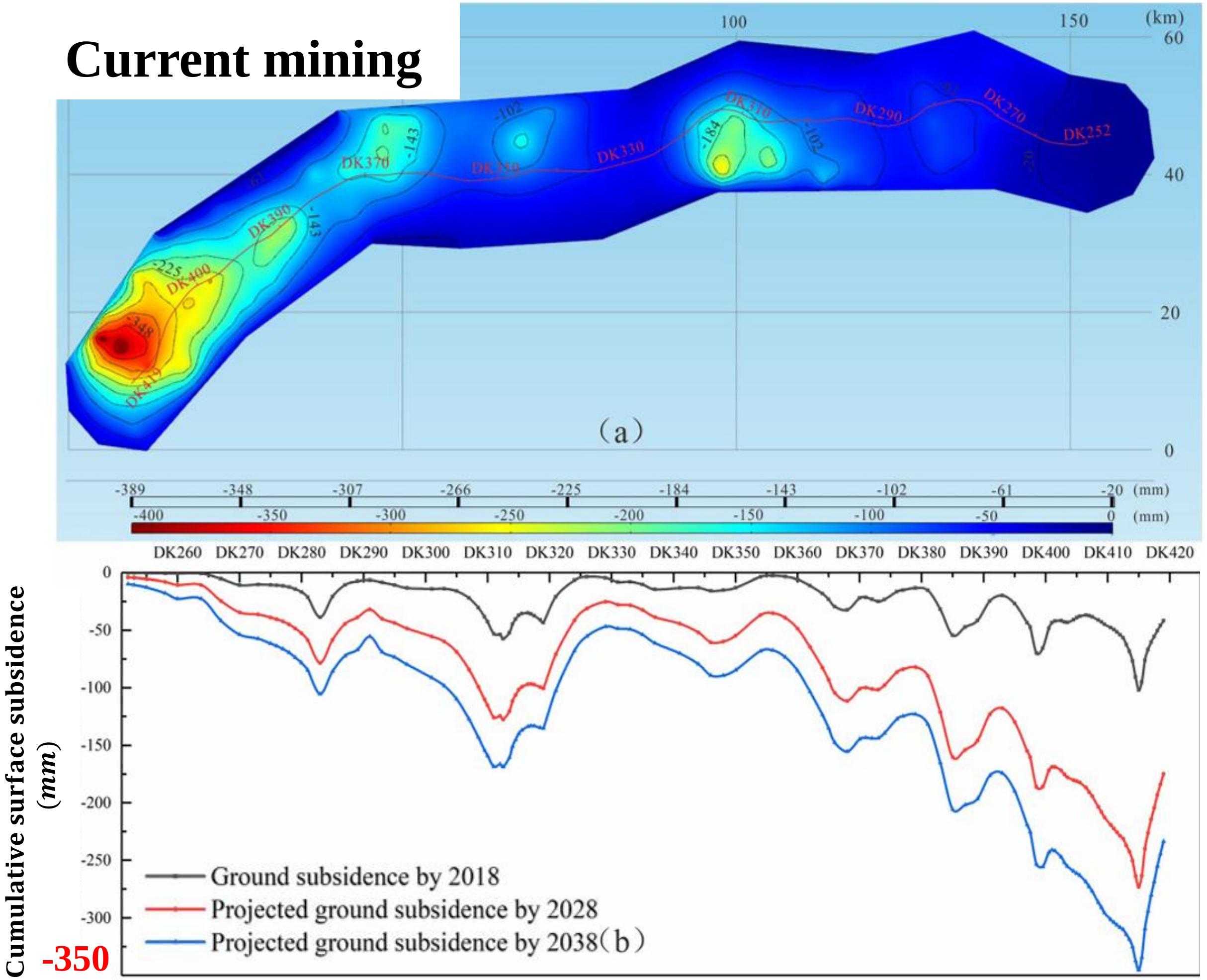


- Simulated and InSAR subsidence show similar spatial patterns.
- High temporal fitting (0.90 to 0.98) between simulation and observation.

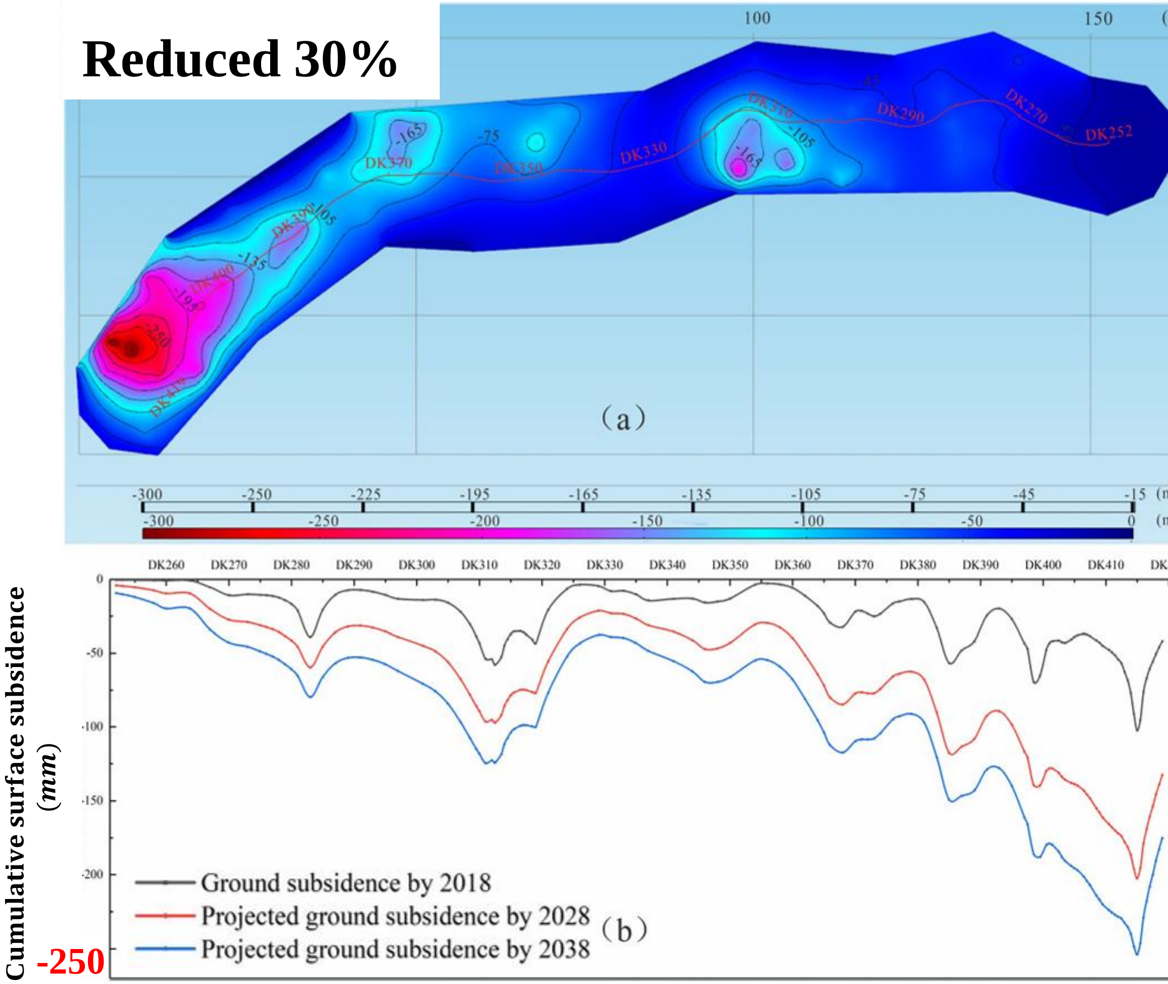
➢ Prediction

Mining schemes	Current mining		Current mining reduced by 30%	
Time/year	2018~2028	2018~2038	2018~2028	2018~2038
Settling velocity (mm/year)	0.38~17.47	0.47~12.73	0.38~11.84	0.45~8.81
Differential subsidence (mm/km)	0.01~10.72	0.01~16.71	0.05~9.56	0.02~11.42

Current mining



Reduced 30%



(Ding et al., 2020)

➢ Objectives

To build a research framework

To verify the effectiveness of GNSS

↓

Estimation of Groundwater Pumping

➢ Data

Geodetic data

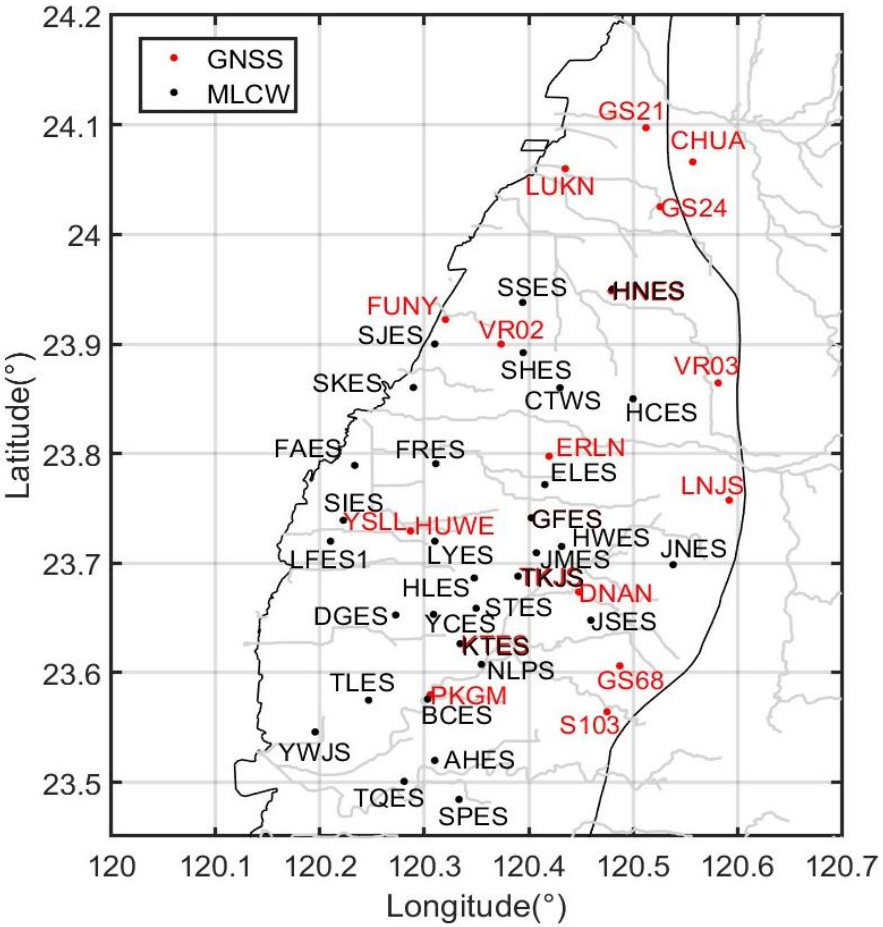
Global Navigation Satellite System(GNSS)

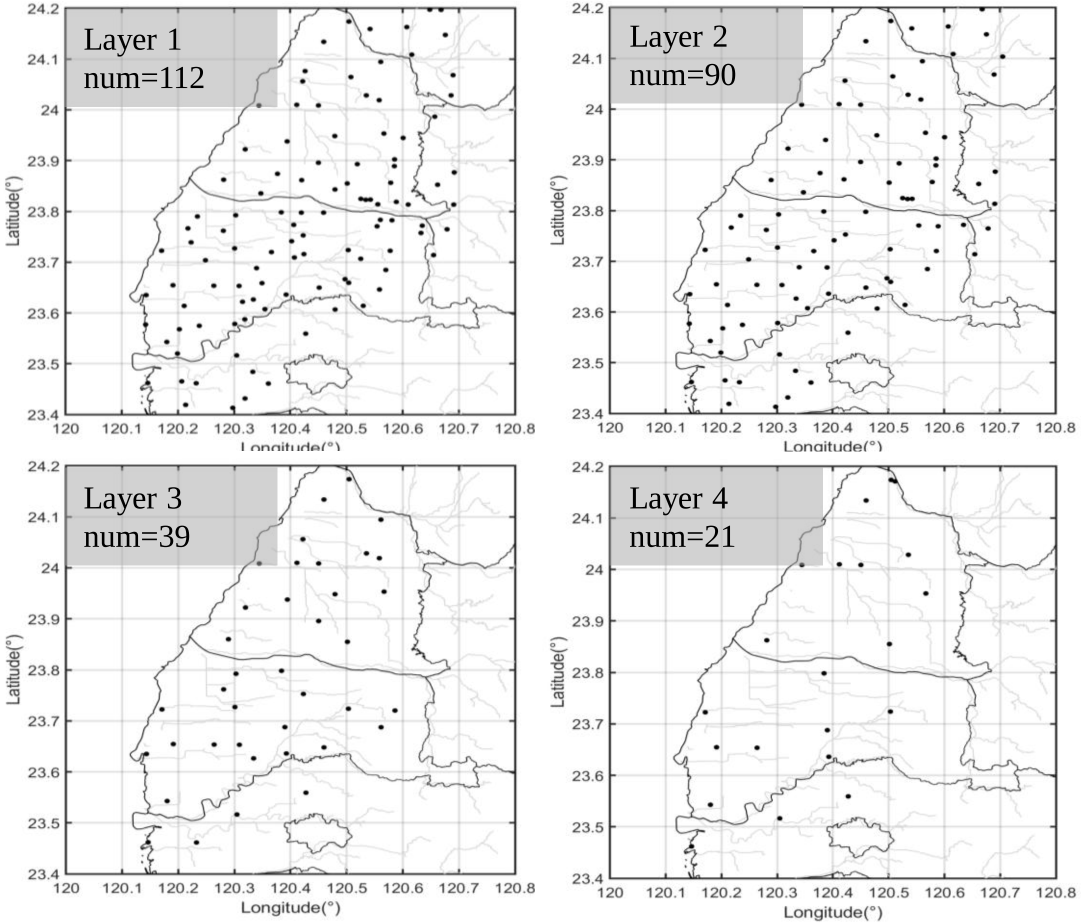
In-situ data

Multi-layer compaction monitoring Well (MLCW)

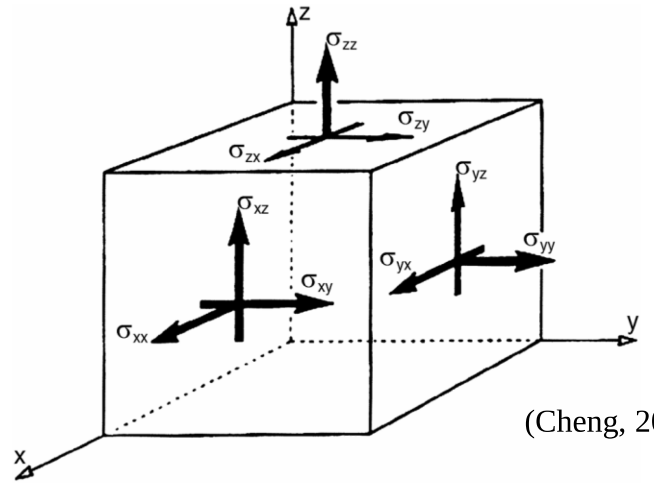
Groundwater data

Groundwater level Well





Governing equation



(Cheng, 2016)

Displacement formulation

- The interplay between solid elasticity, fluid pressure, and body force governs the deformation behavior of the medium.

Internal Elastic Response | **External Driving Forces**

$$\underbrace{G\nabla^2 u_i}_{\text{Shear Contribution}} + \underbrace{\frac{G}{1-2\nu}\frac{\partial^2 u_k}{\partial x_i \partial x_k}}_{\text{Volumetric Contribution}} = \underbrace{\alpha\frac{\partial p}{\partial x_i}}_{\text{Pore Pressure}} - \underbrace{(\rho_s + n\rho_f)g}_{\text{Gravitational Force}}$$

To invert **pore pressure**

To invert **parameters**

To invert **extraction**

G	The shear modulus	kPa
∇^2	The Laplacion operator	$=\frac{\partial}{\partial x^2}+\frac{\partial}{\partial y^2}+\frac{\partial}{\partial z^2}$
u	The displacement	m
i	The direction	$=x,y,z$
v	The Poisson's ratio	
x_i, x_k	The spatial direction	$=x,y,z$
α	Biot's coefficient	
p	The pore water pressure	kPa
ρ_s, ρ_f	The density of solid and fluid	m/d
n	porosity	kN/m^3
g	The external body force	N

Data processing

Constant

Annual oscillation (Seasonal fluctuation)

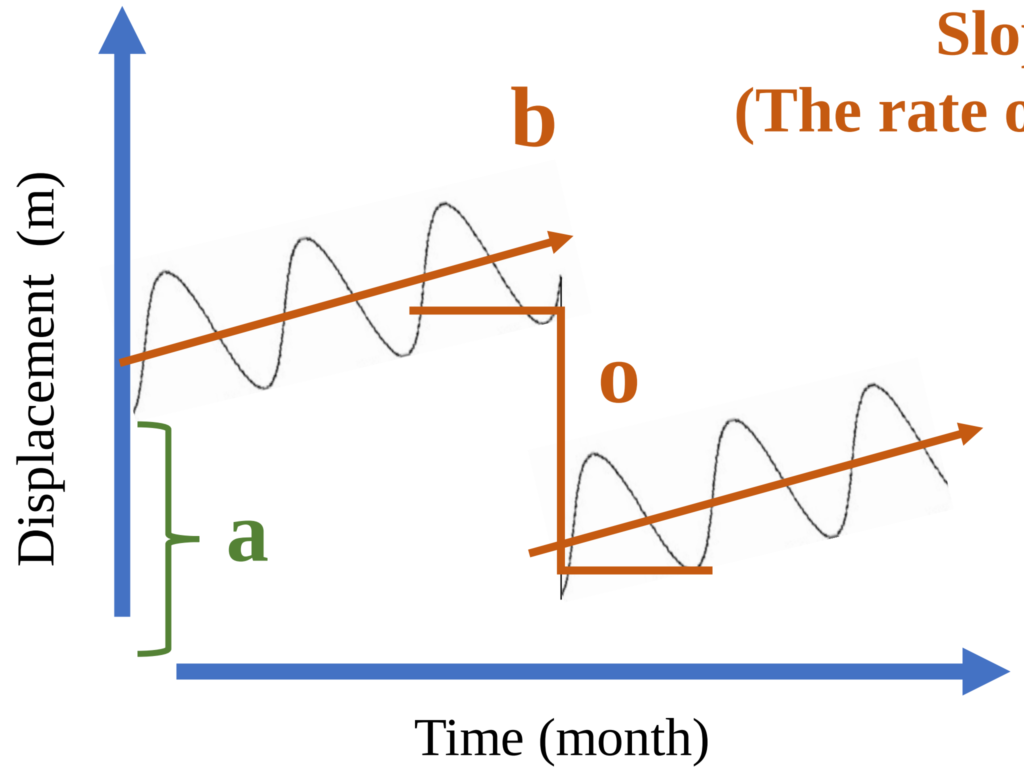
(Hung et al., 2021; Hung et al., 2024)

Displacement data

$$y(t_i) = a + bt_i + \sum_{m=1}^{m_0} c_m \sin(2\pi f_m t_i + \varphi_m) + \sum_{j=1}^{j_0} o_j H(t_i - T_J)$$

Slope (The rate of change)

Sudden jump (step function)



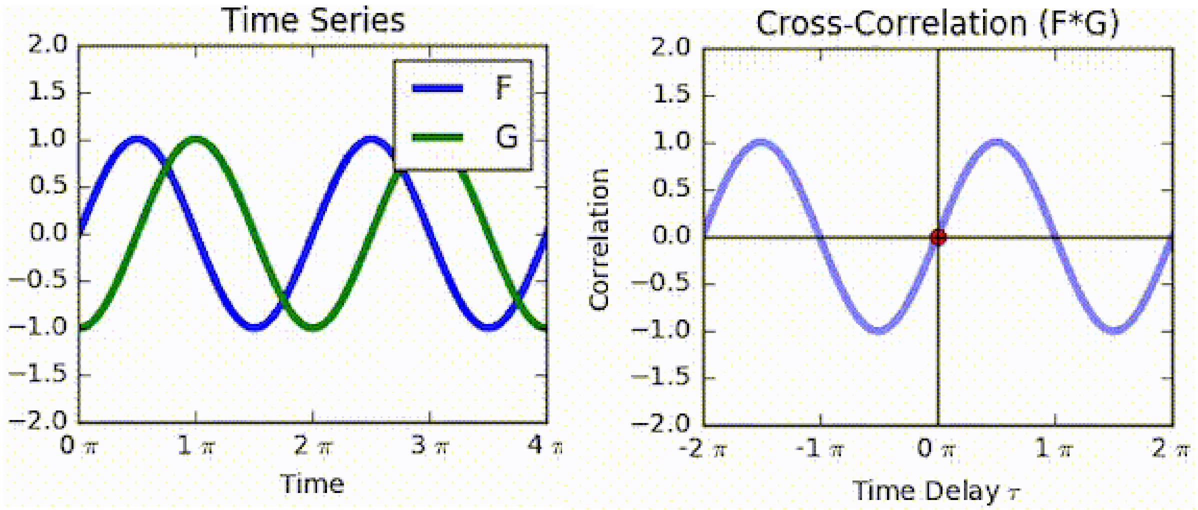
t_i	Time	φ_m	The phase
m_0	The number of frequency	j_0	The number of jump
c_m	The amplitude	o_j	The step function
f_m	The frequency	T_J	The time of jump

➢ Data processing

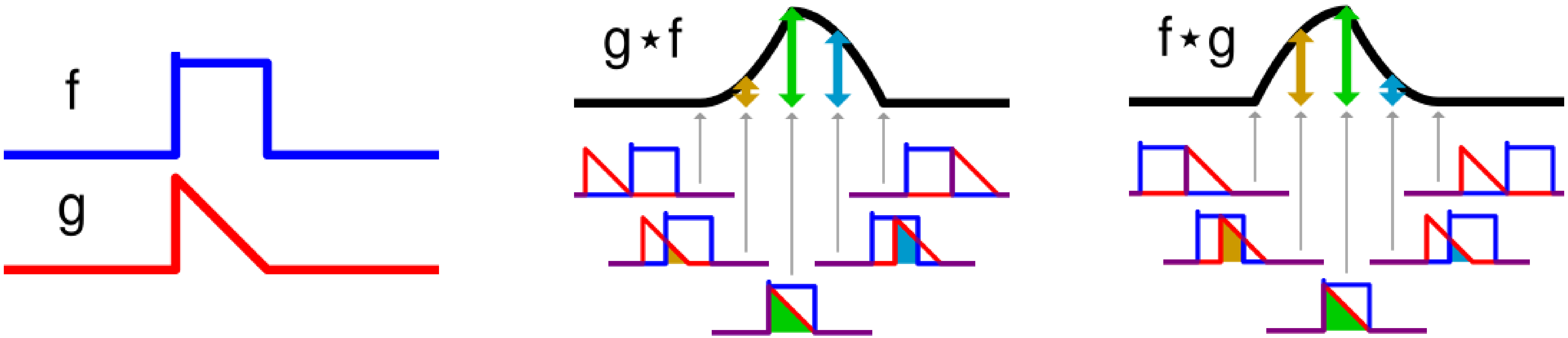
(Hsu et al., 2020)

Cross-correlation coefficients

- To measures the similarity between two time series at different time lags.
- The higher the absolute value indicates more similar the two datasets are.



https://en.wikipedia.org/wiki/Cross-correlation

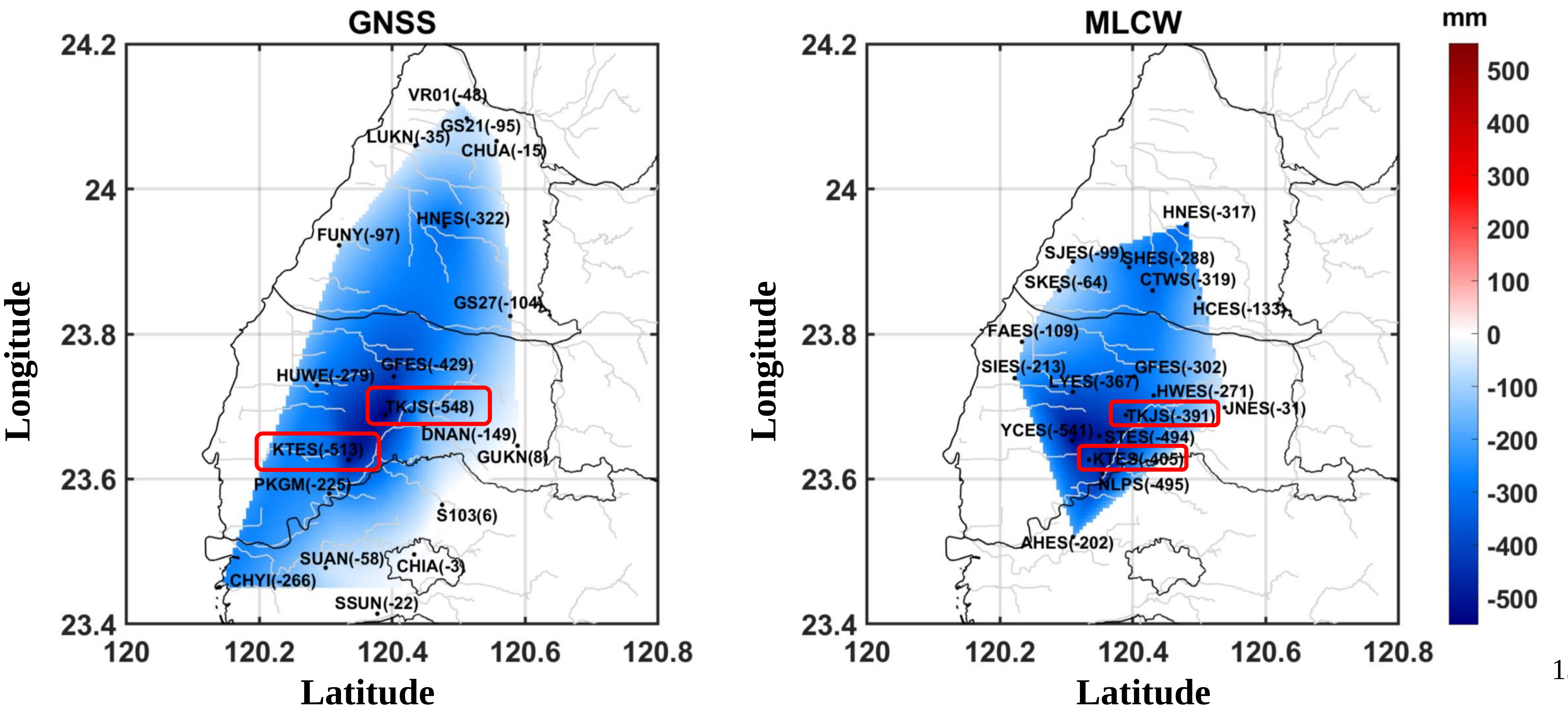


https://en.wikipedia.org/wiki/Cross-correlation

➢ Spatial distribution

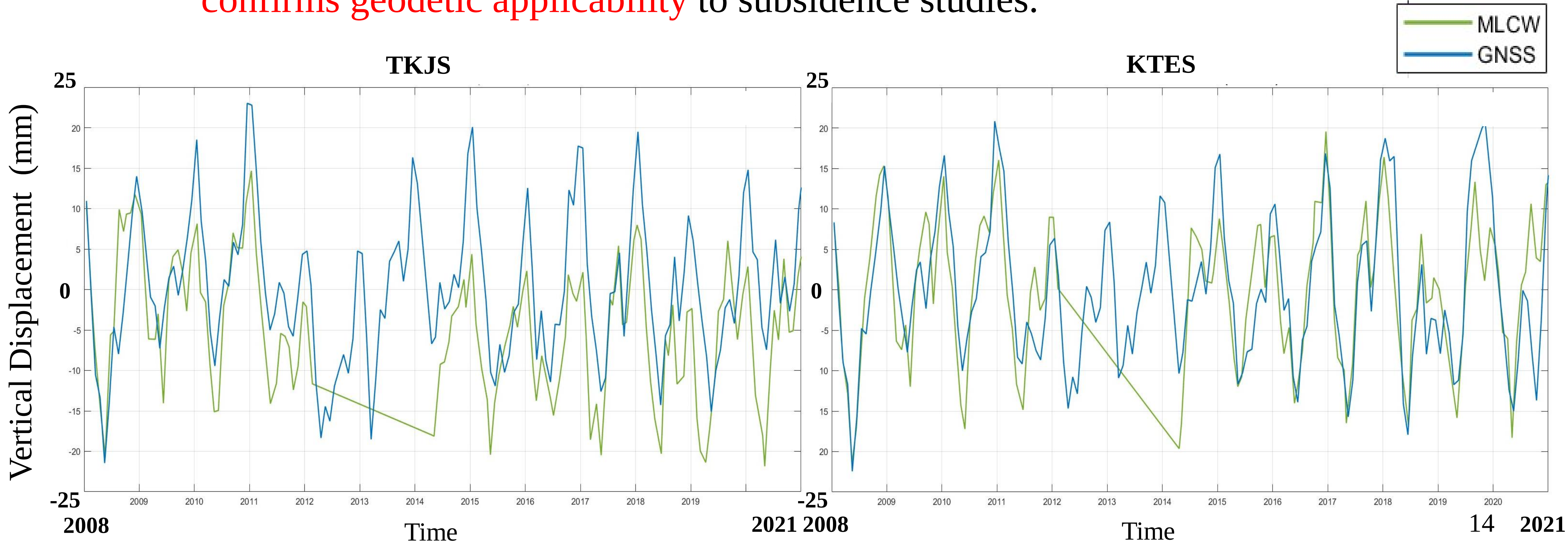
Cumulative compaction during 2008~2019

- Similar spatial patterns between GNSS and MLCW confirm GNSS as an **effective tool** for subsidence monitoring.



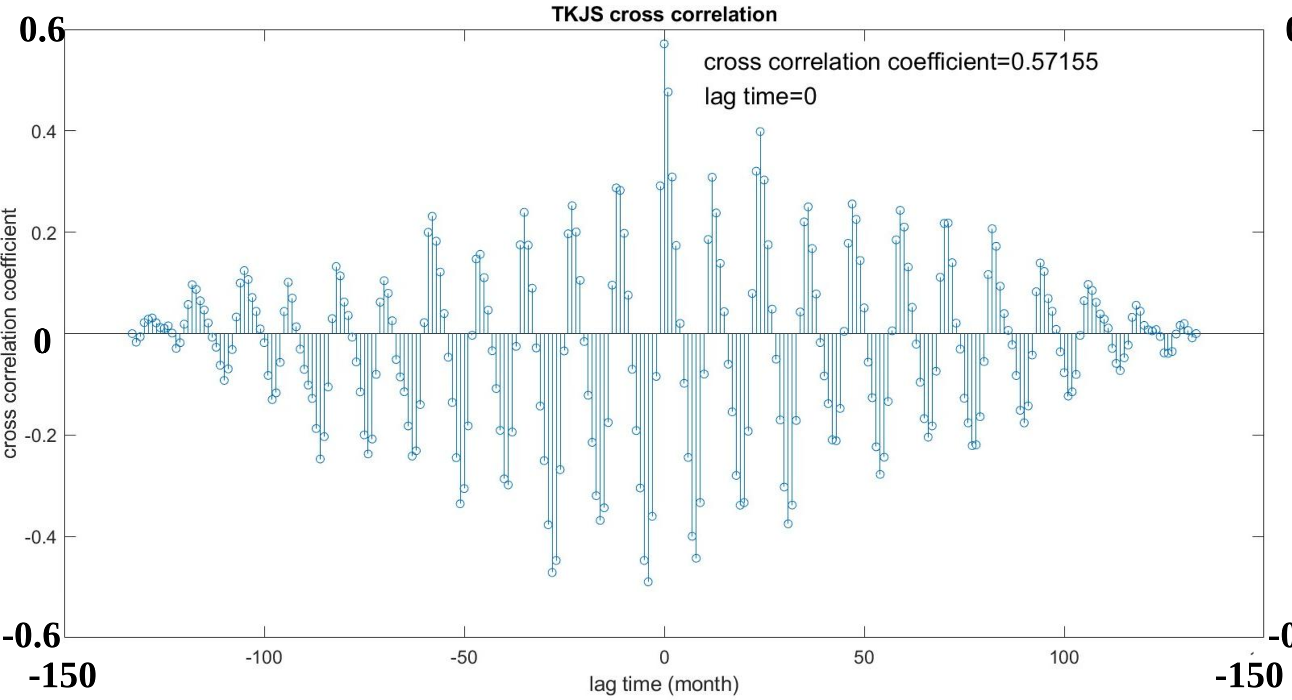
➢ Temporal distribution

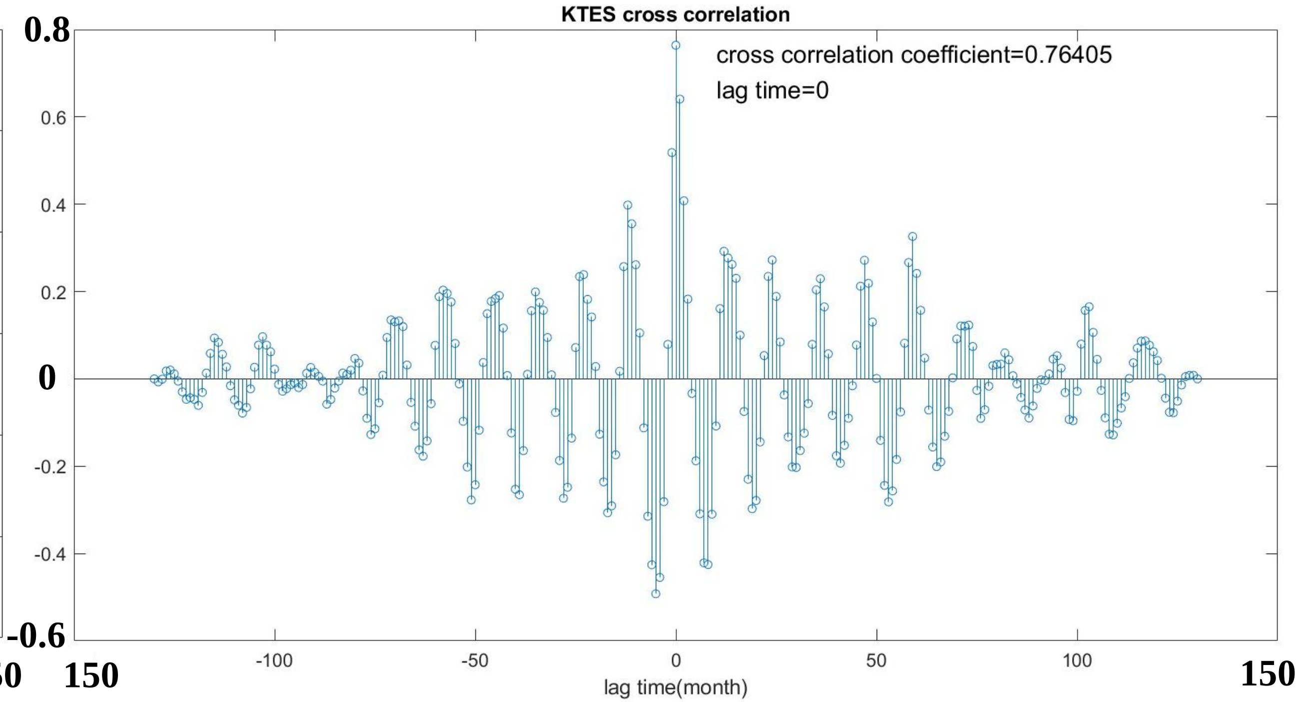
- **Removing long-term linear trends** to focus on elastic deformation.
- Seasonal vertical displacement comparison between **GNSS** and **MLCW** confirms geodetic applicability to subsidence studies.



➢ Temporal distribution

- **Cross-correlation coefficients** ranging from 0.57 to 0.76.
- **Time lag** is zero.





- GNSS displacement shows **strong correlation** with groundwater level changes.

  → Ali et al. (2021)：$R^2 = 0.62 \sim 0.77$.

  → Spatial analysis ： consistent spatial distribution (compare with MLCW).

  → Temporal analysis ： cross-correlation coefficients ranging from 0.57 to 0.76.

  → **GNSS can serve as an effective observation for aquifer system compaction.**

- Simulation validated by **InSAR** and **point-based subsidence**.

  → Ding et al. (2020)：fitting goodness = 0.90 ~ 0.98

  → **The model demonstrates high reliability for long-term subsidence prediction.**

- Land subsidence can be described using **governing equations**.

  → **Elastic poroelasticity model provides theoretical basis.**

➢ Future work

Land subsidence prediction

Groundwater extraction

Layer weighting

Connection

Groundwater level changes ⟷ Groundwater Extraction

Update & Completion

- Data
- Formulation
- Results

Description

Physical parameters ⟷ Geological materials

Reference

1. Ali, M. Z., Chu, H., Tatas, N., & Burbey, T. J. (2021). Spatio-temporal estimation of monthly groundwater levels from GPS-based land deformation. *Environmental Modelling & Software*, 143, 105123. https://doi.org/10.1016/j.envsoft.2021.105123
2. Burbey, T. J. (2001). Stress-Strain analyses for Aquifer-System Characterization. *Ground Water*, 39(1), 128–136. https://doi.org/10.1111/j.1745-6584.2001.tb00358.x
3. Cheng, A. H.-D. (2016). Poroelasticity. *Springer*.
4. Ding, P., Jia, C., Di, S., Wang, L., Bian, C., & Yang, X. (2020). Analysis and prediction of land subsidence along significant linear engineering. *Bulletin of Engineering Geology and the Environment*, 79(10), 5125–5139. https://doi.org/10.1007/s10064-020-01872-1
5. Hung, W., Hwang, C., Sneed, M., Chen, Y., Chu, C., & Lin, S. (2021). Measuring and interpreting multilayer Aquifer-System compactions for a sustainable Groundwater-System development. *Water Resources Research*, 57(4). https://doi.org/10.1029/2020wr028194
6. Hung, W., Hwang, C., Lin, S., Wang, C., Chen, Y., Tsai, P., & Lin, K. (2024). Exploring groundwater depletion and land subsidence dynamics in Taiwan's Choushui river alluvial fan: insights from integrated GNSS and hydrogeological data analysis. *Frontiers in Earth Science*, 12. https://doi.org/10.3389/feart.2024.1370626
7. Hsu, Y., Fu, Y., Bürgmann, R., Hsu, S., Lin, C., Tang, C., & Wu, Y. (2020). Assessing seasonal and interannual water storage variations in Taiwan using geodetic and hydrological data. Earth and Planetary Science Letters, 550, 116532. https://doi.org/10.1016/j.epsl.2020.116532
8. Nguyen, T., Ni, C., Hsu, Y., Chen, P. R., Hiep, N. H., Lee, I., Lin, C., & Gosselin, G. (2024). Quantitative evaluations of Pumping-Induced land subsidence and mitigation strategies by integrated remote sensing and Site-Specific hydrogeological observations. *Remote Sensing*, 16(20), 3789. https://doi.org/10.3390/rs16203789

Thanks for your attention.