HS 8.2.5

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Integration of DInSAR Land Subsidence Observations with a Coupled Groundwater Flow and Geomechanical Modeling Approach

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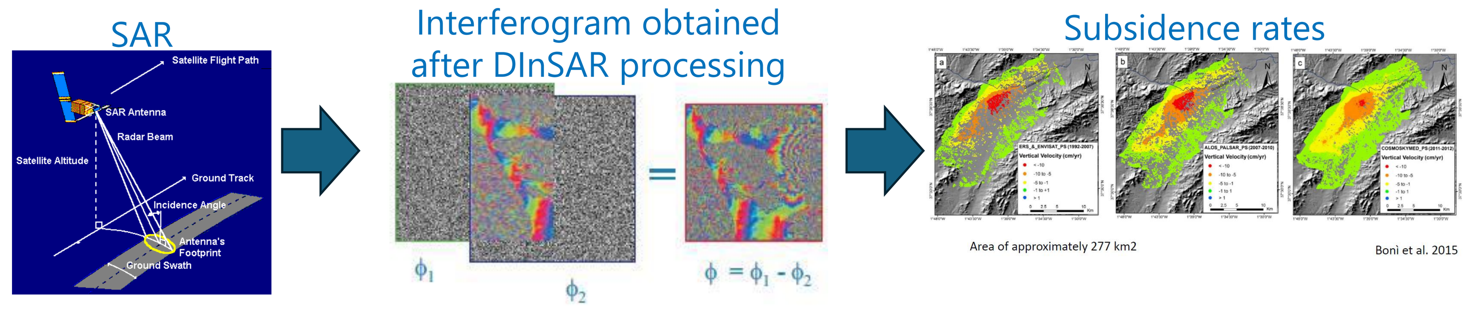
1. Introduction

- Land subsidence (LS) resulting from **groundwater over-exploitation** has been documented globally in many locations.
- LS is a gradual lowering of the land surface as a consequence of pore water pressure drops in fine-grained sediments (e.g. clay).
- Major environmental impacts:
  - Damages to buildings and infrastructure
  - Disruption of water hydraulics
  - Increased flood risk and more frequent inundation
  - Aquifer contamination
  - Land loss, salinization
- Interferometric synthetic aperture radar (InSAR) technology has significantly enhanced the capability of measuring LS with a large spatial coverage.

What are InSAR Observations?

- Synthetic Aperture Radar (SAR) is a satellite instrument that emits electromagnetic pulses (~µm wavelength) to remotely measure earth's ground elevation.
- Differential Interferometric SAR (DInSAR): SAR images can be processed through DInSAR methods to temporally analyze ground surface deformations processes.
- Various DInSAR processing methods (algorithms): P-SBAS, FASTVEL, CPT etc.



2. Research Question

Can a **groundwater flow model calibration** be improved with the use of **InSAR**-based land subsidence observation data **as additional calibration targets**?

3. Objectives

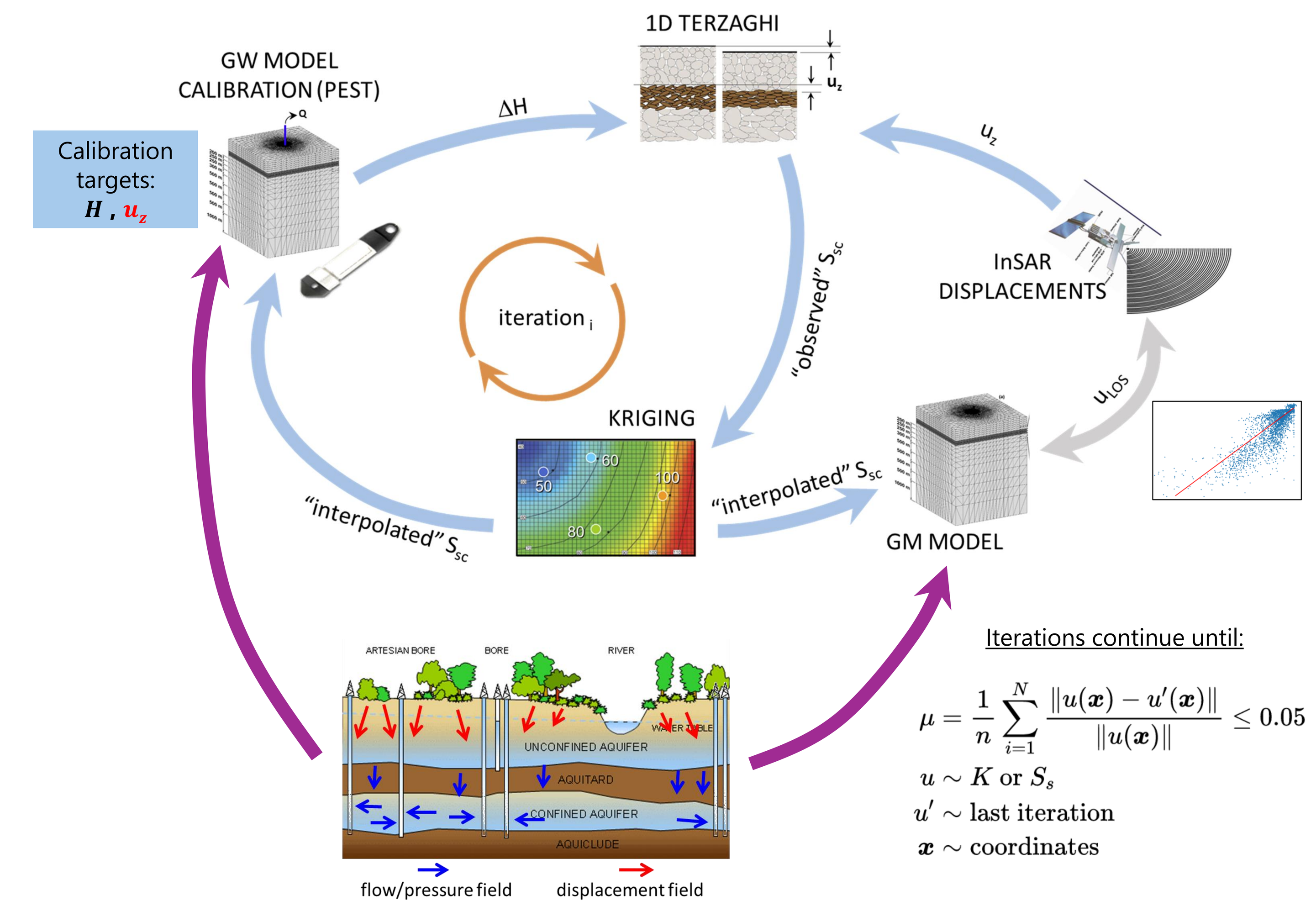
I. To **characterize aquifer hydrogeological properties** from InSAR-derived land subsidence rates for an over-exploited alluvial aquifer using a **one-way coupled modeling** approach.

II. To **improve parameter estimation** by re-calibrating a previously set up groundwater flow model using InSAR data.

III. To obtain a flow model that can **more accurately** forecast **groundwater storage** depletion/accumulation.

4. Methods

One-way Coupled Modeling Between Groundwater Flow and LS



- MODFLOW-2005 flow model → head change, ΔH
- Geomechanical model (GEPS3D)→ vertical land displacement, Δu_z
- 1-D Terzaghi consolidation equation: $S_s = \Delta u_z / (\Delta H \cdot d)$ (storage; head change; land subsidence; thickness)
- InSAR observations, Δu_z
- Kriging

Numerical Models

Groundwater flow (GW) model (MODFLOW)

- **Purpose**: inferring permeability and providing ΔH
- 242 rows × 188 columns × 5 layers, 150x150 m resolution
- Simulation period: 10/2013–12/2021, 99 monthly stress periods,
- BCs: lateral recharge (GHB), surface water (RIV)
- Rainfall recharge (RCH) obtained with an earth-observation dataset supported water balance approach

Geomechanical (GM) finite-element model (GEPS3D)

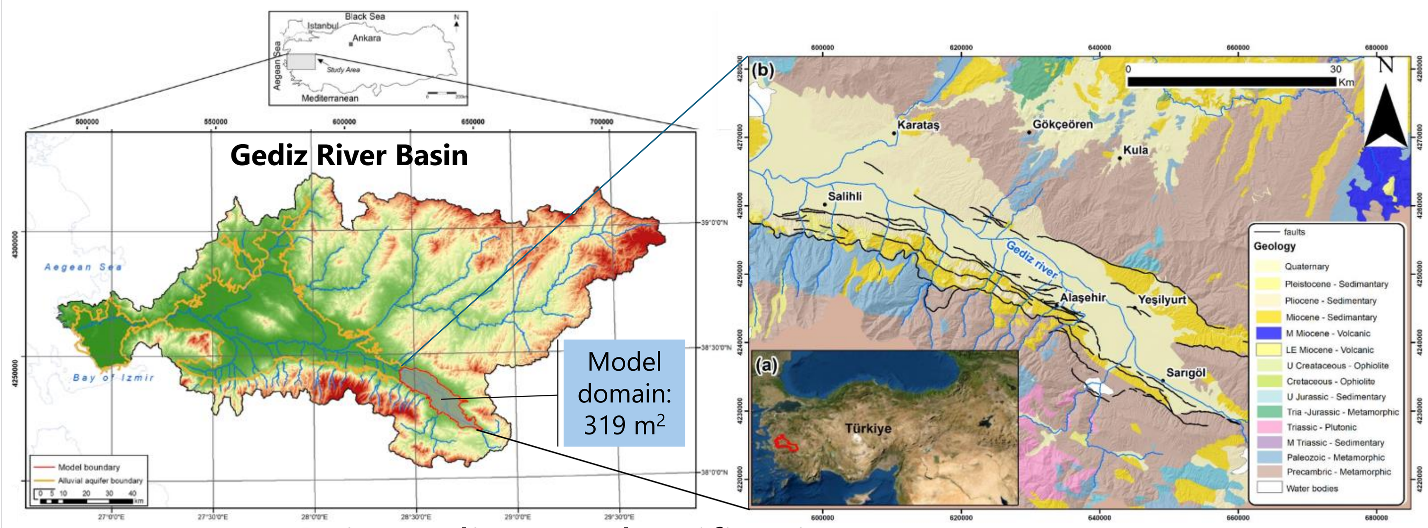
- **Purpose**: validating the interpolation results of aquitard S_s
- Same as the GW model grid + model boundaries extended outward to apply boundary conditions
- Simulation period: 1/2017–8/2021 (2-year warm-up transition + InSAR observation period = 56 months)

GW Flow Model Calibration

- Manual (trial & error) followed by PEST parameter estimation
- Piezometric level time series from 26 monitoring wells (n=476)

5. Study Area: Gediz River Basin (Turkiye)

Alaşehir-Sarıgöl Alluvial Aquifer

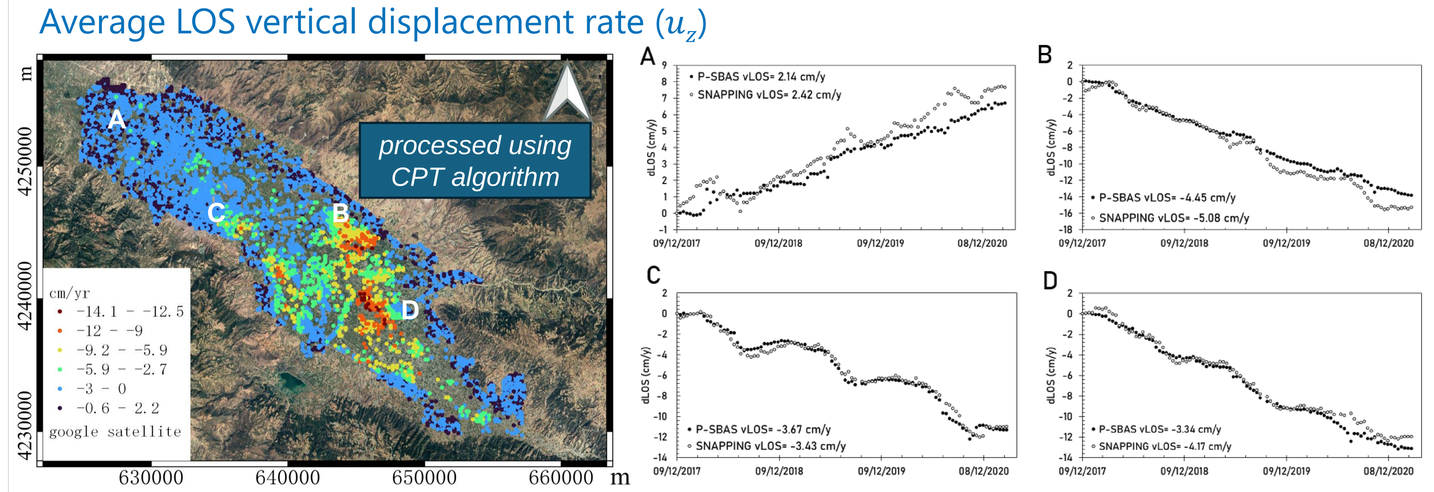


- Köppen-Geiger climate classification: Csa (warm temperate, dry & hot summer)
- Mean annual precipitation (1992 – 2021) = 617 mm
- Alluvial aquifer developed in the WNW-ESE directional Gediz graben
- Alluvial aquifer has a high groundwater potential
- Provides most of the irrigation water for vineyards
- Avg. groundwater pumping rate (2013 – 2022) = 81.66 Mm³/yr

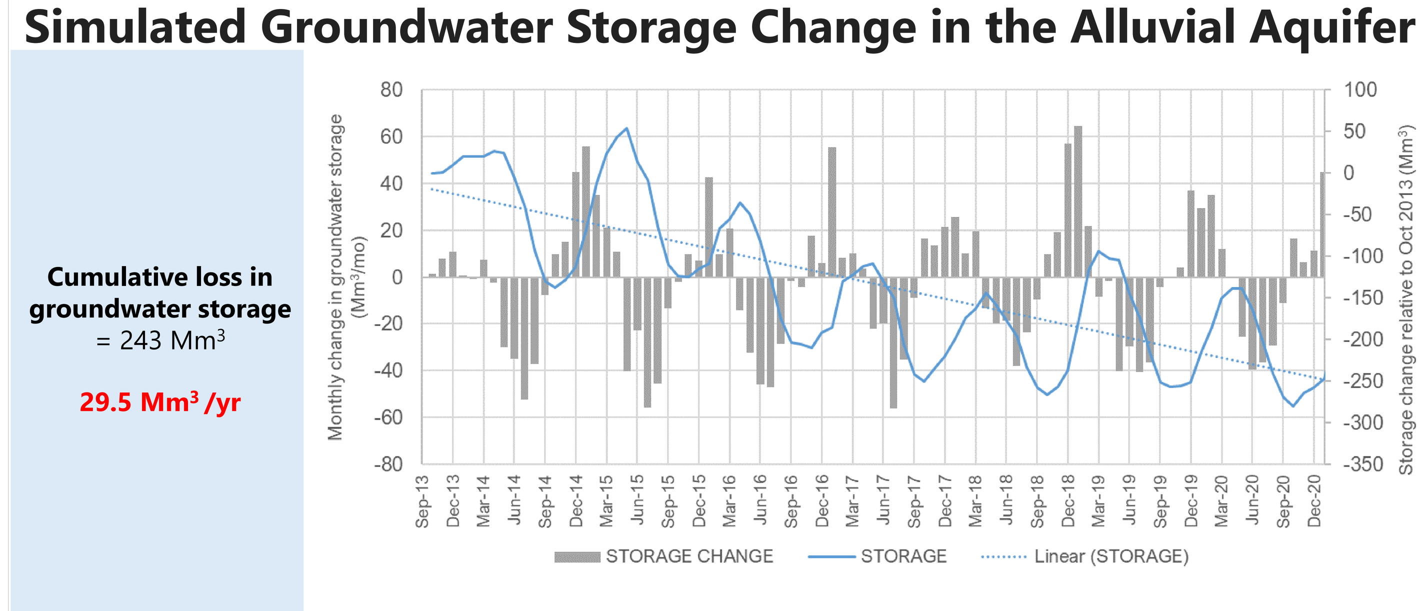
Land Surface Displacement in the Study Area

- Detected land subsidence rates
  - PSBAS and SNAPPING = 4.5 – 5.1 cm/yr
  - CPT = 10 cm/yr

Average LOS vertical displacement rate (u_z)

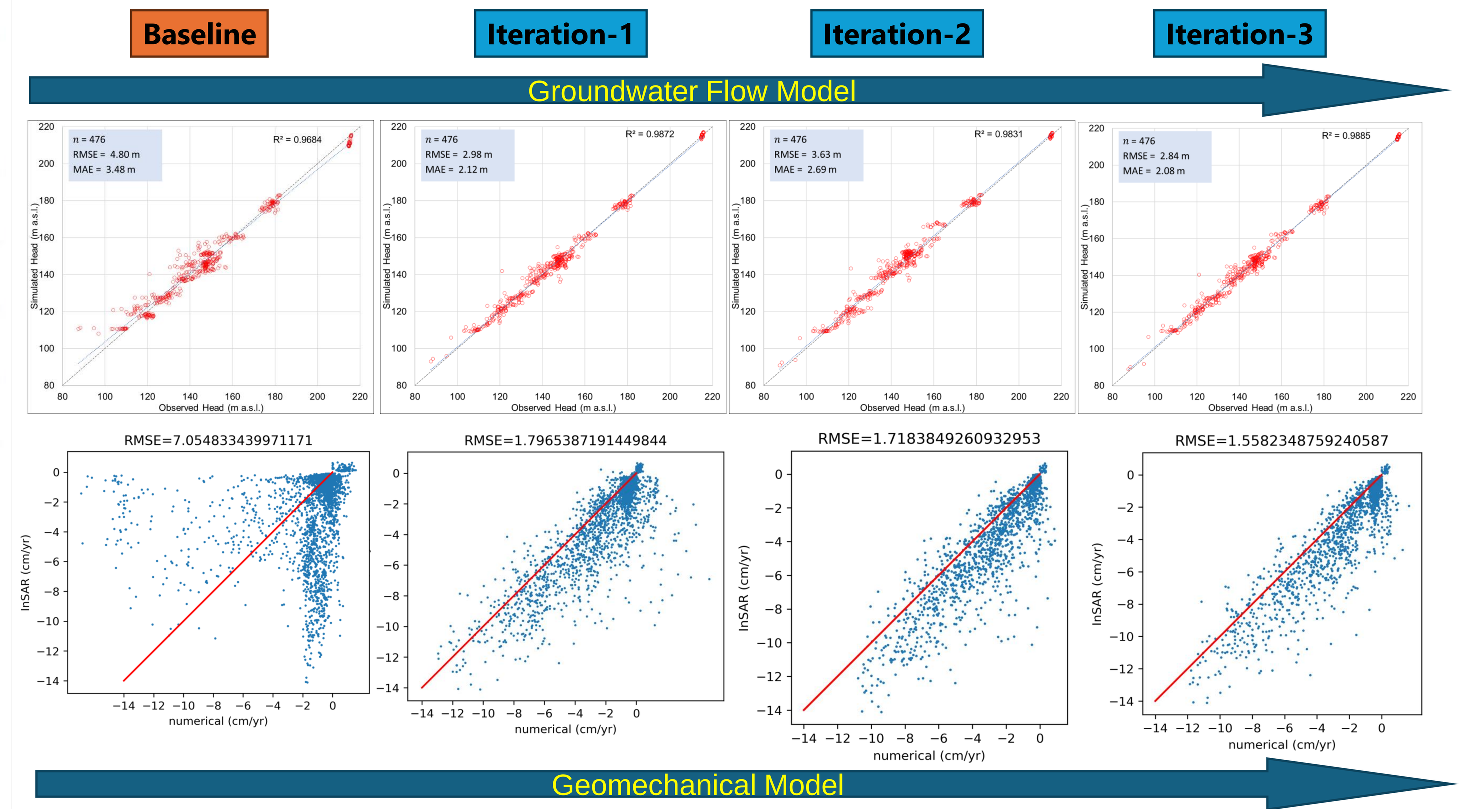


Simulated Groundwater Storage Change in the Alluvial Aquifer



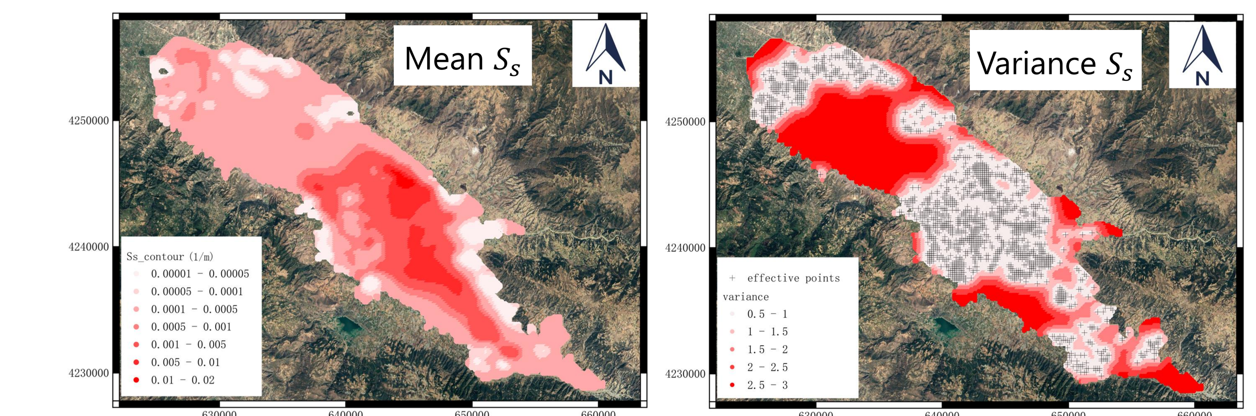
6. Results

Improvement in Model Performances after One-Way Coupled Calibration with InSAR data

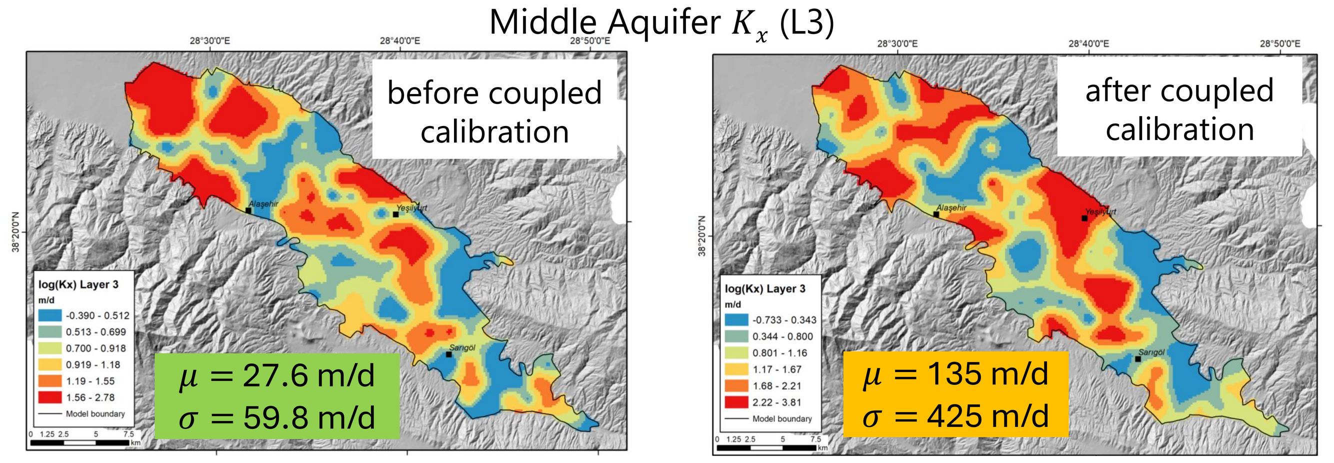


Parameter Estimation: Specific Storage & Hydraulic Conductivity

Aquitard S_s (L2 and L4)



Middle Aquifer K_x (L3)



7. Conclusions

- The proposed calibration approach integrating **InSAR-derived information, GW-GM modelling and a geostatistical method**, offers an effective solution for estimating an aquifer's hydraulic parameters.
- The match of the measured InSAR datasets allows to **derive spatial distribution of parameters** (especially specific storage), which are invaluable for **aquifer management**.
- Integrating numerical methods, geostatistical techniques, and InSAR measurements could provide deeper insights into aquifer properties and could lead to a more comprehensive understanding of aquifer responses to anthropogenic activities.

References

- G. Bru, C. Guardiola-Albert, P. Ezquerro, and M. Béjar-Pizarro. A-DInSAR processing in Gediz River Basin (Turkey). Technical report, RESERVOIR Project Deliverable D3.3, Madrid, Spain, 2021.
- A. Elçi, E. A. Batkan, B. Caylak, M. M. Bayirtepe, and A. H. Ören. Groundwater flow model for the Gediz River Basin alluvial aquifer (Turkiye). Technical report, RESERVOIR Project Deliverable D5.3, Izmir, Turkiye, 2022.
- M. I. Navarro-Hernández et al., "Monitoring land subsidence induced by tectonic activity and groundwater extraction in the eastern Gediz River Basin (Türkiye) using Sentinel-1 observations," Eng. Geol., vol. 327, p. 107343, 2023.

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