Application of a Multidisciplinary Approach to Assess Consolidation in Different Geological Layers at a Local Scale in Antwerp

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- **LASUGEO Project:** The LASUGEO project: monitoring LAnd SUbsidence caused by Groundwater exploitation through gEOdetic measurements

- **Our Focus:** Ground vertical Displacement: A key issue observed particularly in Antwerp.

- **Objectives:** Identifying the complex mechanisms causing ground displacements in Antwerp, using a multidisciplinary approach.

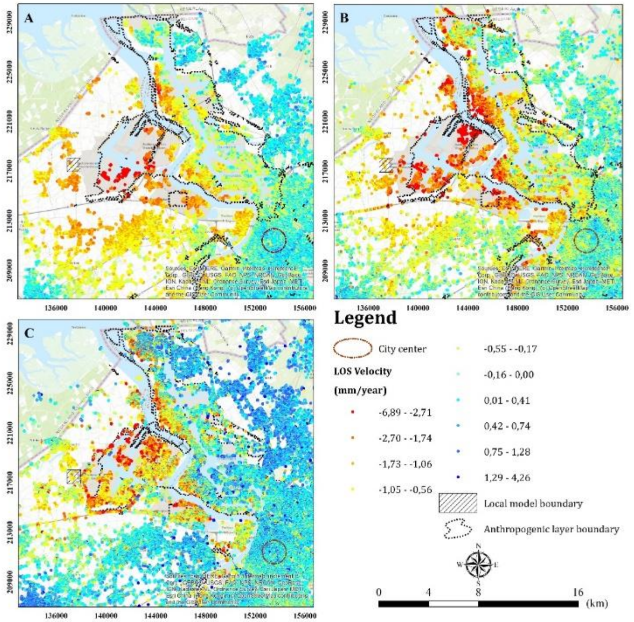
- **Methodology Overview:** 1D-geomechanical model coupled to an hydrogeological model and comparison of the simulation results of deformation with the results from the Persistent Scatterer Interferometry (PSI) approach.

Introduction and Context | Methods and Approaches | Data and Measurements | Results and Comparison | Conclusions + Future Work | Acknowledgments and Questions

- **Prior research:** Ground vertical displacement monitoring with Persistent Scatterer Interferometry (PSI) in Antwerp harbor and Antwerp city *.

A: ERS dataset (1992-2001)
B: ENVISAT dataset (2003-2010)
C: Sentinel-1A dataset (2016-2020)

Location	Average LOS velocity (ERS) mm/year	Average LOS velocity (Envisat) mm/year	Average LOS velocity (Sentinel) mm/year
City center	0.002	-0.06	-0.6
Harbour	-0.83	-2.71	-1.62



- **Identified gaps:**

1) All the deformation is linked to the presence of the Anthropogenic layer
2) Not exploring other possible drivers of subsidence.

* Declercq, P. Y., Gérard, P., Pirard, E., Walstra, J., & Devleeschouwer, X. (2021). *Long-term subsidence monitoring of the Alluvial plain of the Scheldt river in Antwerp (Belgium) using radar interferometry. Remote Sensing, 13(6), 1160.*

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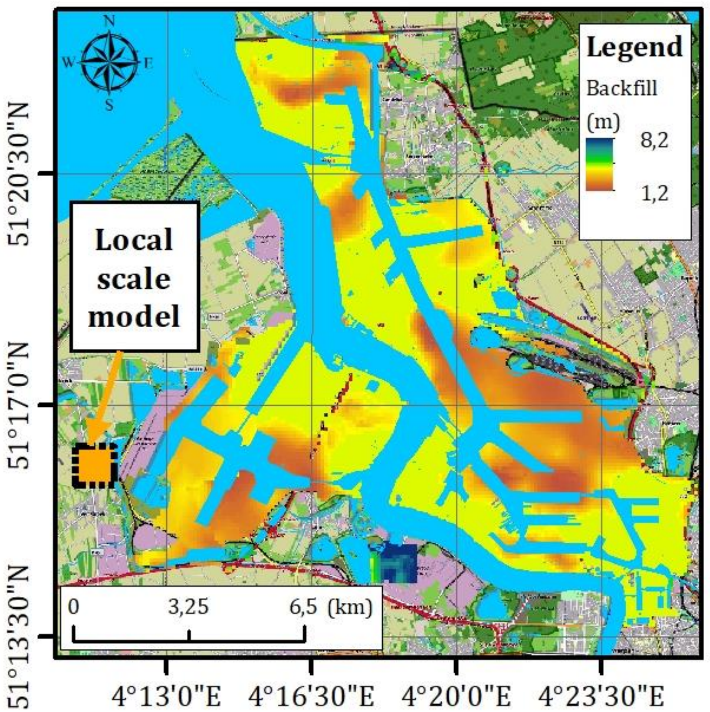
- **Current research:** 3D-hydrogeological model (MODFLOW) coupled to 1D-geomechanical model (SUB package) at the local scale of 1 by 1 km^2
- Effective Stress and Deformation: Linearized relation assumption

- **Site selection rationale:**

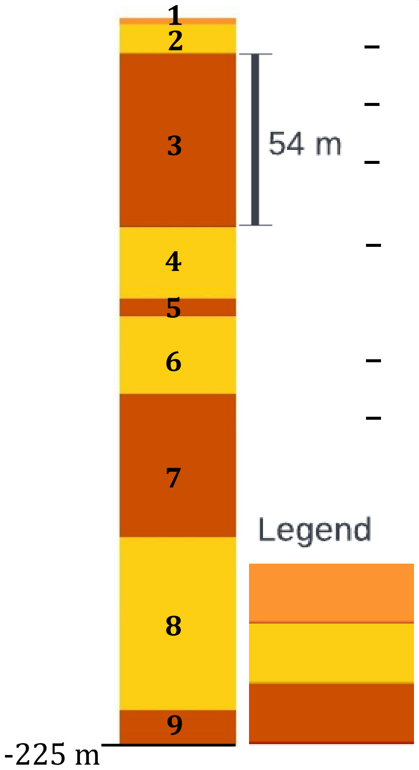
1) Absence of anthropogenic layer;
2) Notable decrease in head level in the Oligocene aquifer;
3) Available deformation data

- **Numerical simulations:** pore pressure variations during the simulation and coupled changes of effective stress inducing subsidence

- **Comparison:** Comparison of deformation simulated in 1D-geomechanical model with estimated vertical ground displacement by PSI time series generated from Envisat datasets (2007-2010).

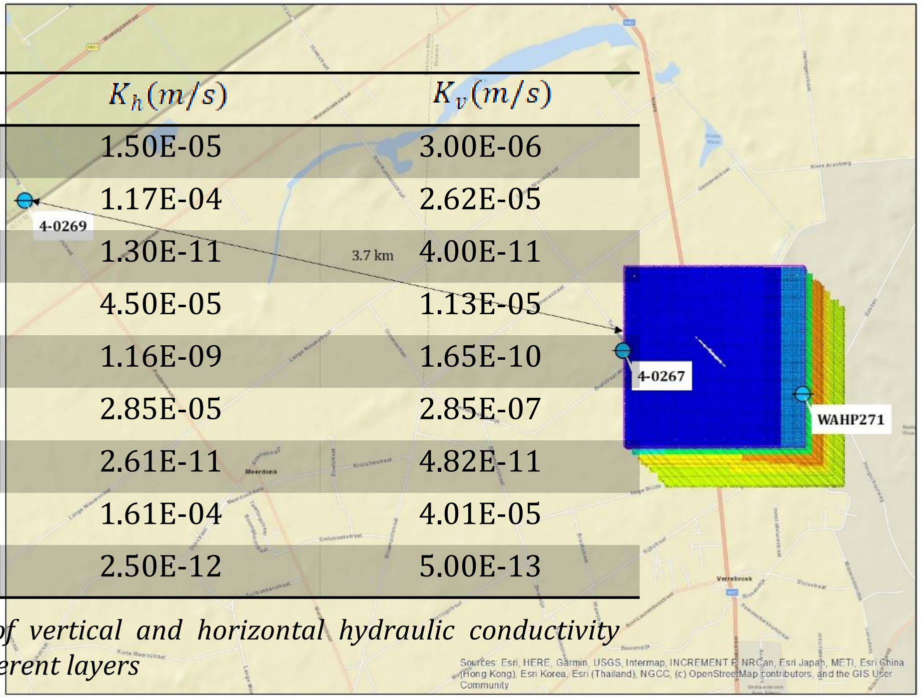


- **Hydrogeological data**
  1. **Hydrogeological units:** 9 identified hydrogeological units
  2. **Piezometric data:** Collected from 3 different piezometric wells
  3. **Grid Dimensions:** Regular grid in XY planes with cell size of 100 m^2
  4. **Hydrogeological parameters:** Collected from previous regional groundwater modelling studies
  5. **Simulation period:** 2007-2016



- WAHP271: Monitoring water level in Layers 1,2.
- 4-0267: Monitoring water level in Layers 4,8.
- 4-0269: Monitoring water level in Layers 6.

- Prescribed heads on lateral boundaries in layers 1,2,4,6,8
- No flow on the bottom and on the top
- No flow on the other lateral boundaries



Layer	$K_h(m/s)$	$K_v(m/s)$
Layer 1	1.50E-05	3.00E-06
Layer 2	1.17E-04	2.62E-05
Layer 3	1.30E-11	4.00E-11
Layer 4	4.50E-05	1.13E-05
Layer 5	1.16E-09	1.65E-10
Layer 6	2.85E-05	2.85E-07
Layer 7	2.61E-11	4.82E-11
Layer 8	1.61E-04	4.01E-05
Layer 9	2.50E-12	5.00E-13

Table 1: Values of vertical and horizontal hydraulic conductivity parameters in different layers

- **Geotechnical data:** Swelling/Compression Constants → Elastic/Inelastic Skeletal Storage Coefficient

Reports of oedometer tests on samples from boreholes located on the Eastern side

Oedometer tests were conducted on Boom clay samples from boreholes in Mol and Essen (at a distance of 79 and 29 km from the local model)*

As layer 2 (similar lithology)

Oedometer tests were conducted on Ypresian clay samples from boreholes located in Kallo (at a distance of 7 km from the local model)**

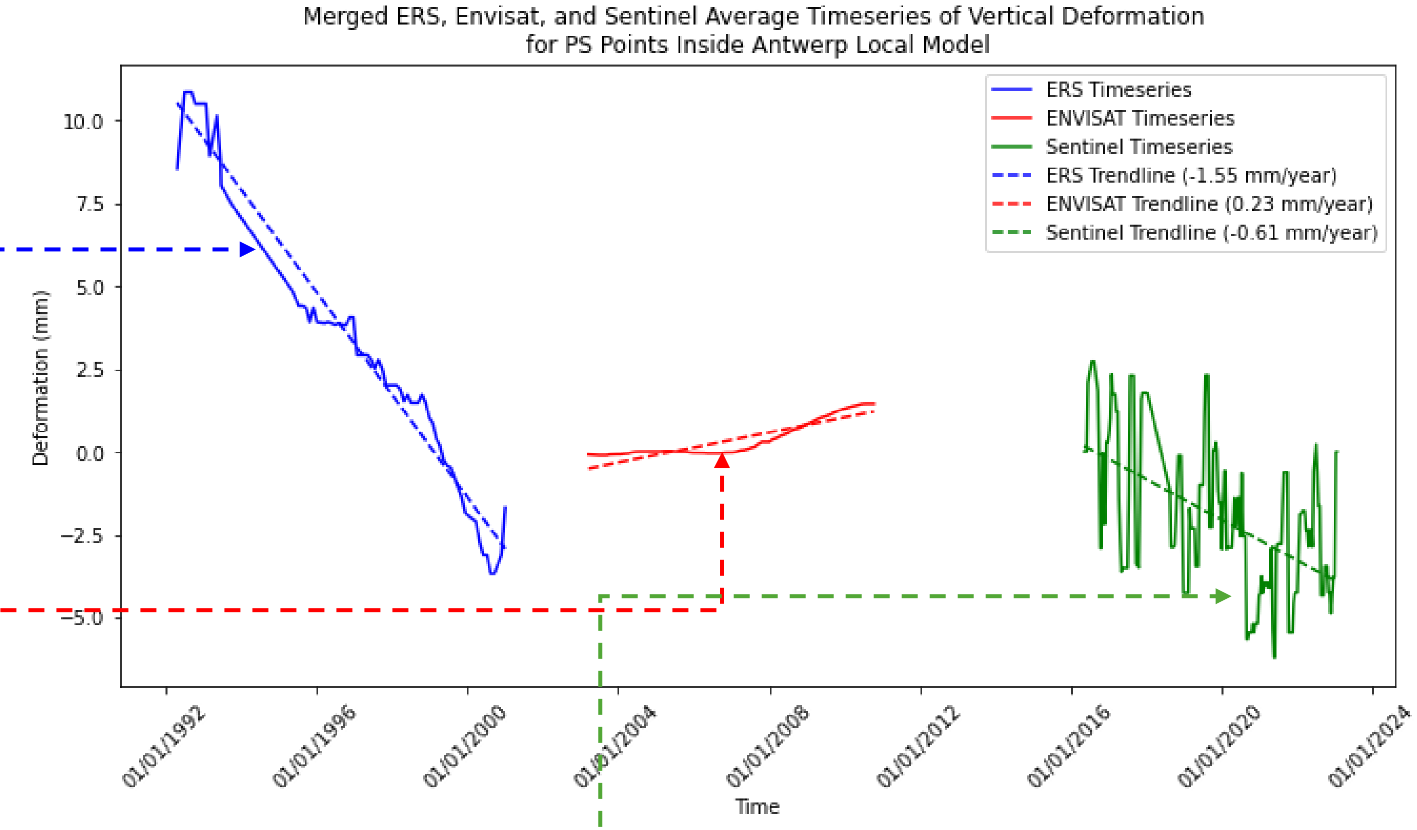
As layer 7 (Similar lithology)

Deng, Y. F., Tang, A. M., Cui, Y. J., Nguyen, X. P., Li, X. L., & Wouters, L. (2011). Laboratory hydro-mechanical characterisation of Boom Clay at Essen and Mol. Physics and Chemistry of the Earth, Parts A/B/C, 36(17-18), 1878-1890.

***Nguyen, X. P., Cui, Y. J., Tang, A. M., Li, X. L., & Wouters, L. (2014). Physical and microstructural impacts on the hydro-mechanical behavior of Ypresian clays. Applied clay science, 102, 172-185. Dassargues, A. (2018). Hydrogeology: groundwater science and engineering. CRC Press.*

Introduction and Context | Methods and Approaches | **Data and Measurements** | Results and Comparison | Conclusions + Future Work | Acknowledgments and Questions

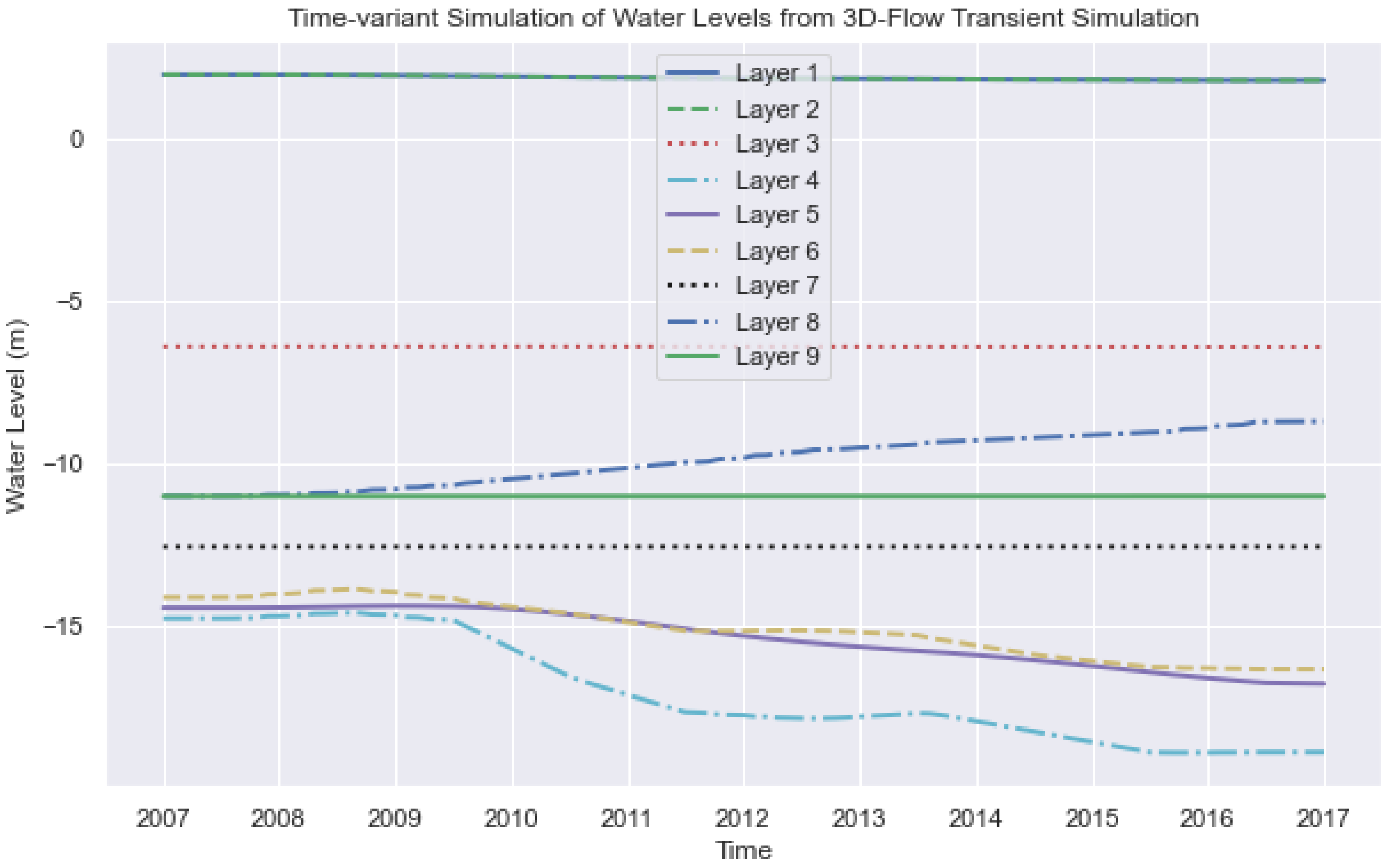
Radar Data	Interferogram generation	PSI Analysis
ERS (1992-2001)	→ Doris →	StaMPS
Envisat (2003-2010)	→ Doris →	StaMPS
Sentinel-1A (2016-2023)	→ ISCE →	StaMPS



- **3D-Flow Transient Model results**

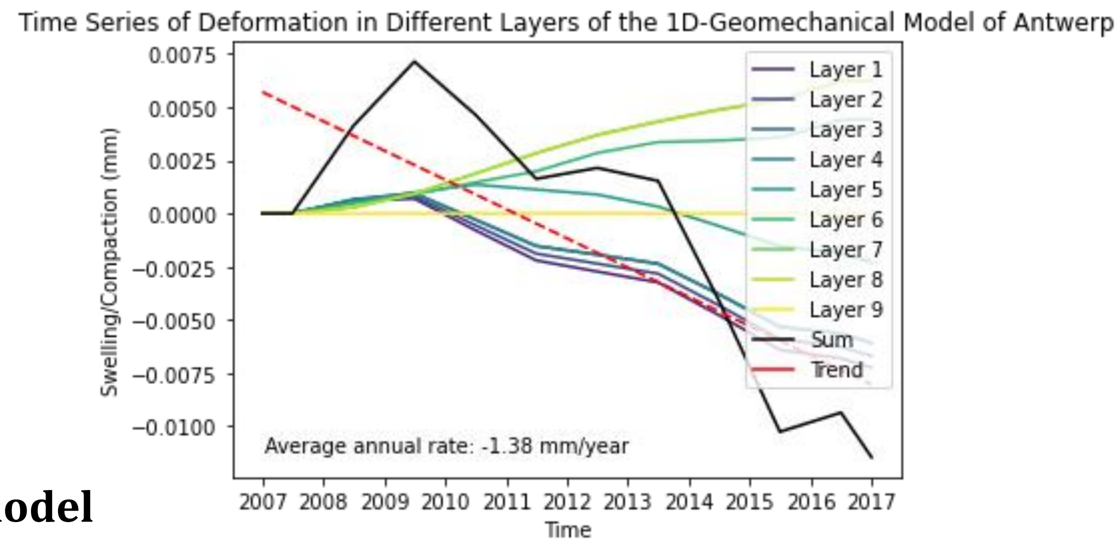
1. Significant head decline in Ruisbroek-Berg aquifer (Layer 4) and rise in Wemmel-Lede aquifer and sands of Brussels (Layer 8).

2. Minor fluctuations in aquitard layers.



- **Geomechanical model: compaction and rebound**

1. Top five layers: observable compaction
2. Deepest four layers: evident rebound
3. Pronounced consolidation and rebound



- **Limitations in ENVISAT data and 1D-Geomechanical model comparison**

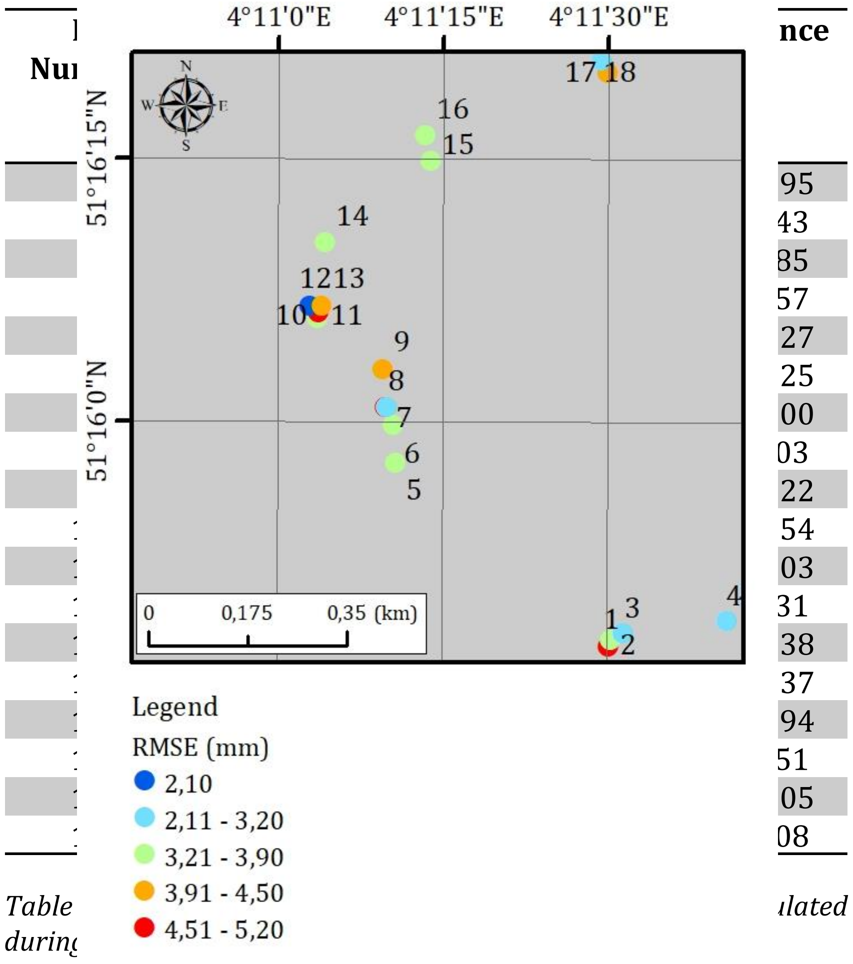
1. Unmatching data periods: model simulation from 2007-2016, ENVISAT data from 2003-2010→ comparison period limited to only three years

2. Initial state of equilibrium in the geomechanical model → the starting stage of the model's time series of deformation may be unreliable

- **ENVISAT Data and 1D-Geomechanical model comparison**

1. Towards the end of the period, the geomechanical model results become more meaningful → Absolute cumulative values simulated in the model and observed by PSI (from ENVISAT) at the end of the comparison period are compared

2. RMSE between PSI Displacement and Model Simulation (2007-2010) for 18 PS points detected in ENVISAT data



- **Take-home messages**

1. The 3D-flow transient model showed declining piezometric heads in the upper six layers and increasing heads in the three deepest layers for the period 2007-2016.

2. The geomechanical model indicated compaction in the top five layers and rebound in the deepest four layers.

3. The PSI displacement and the model cumulated displacement show reasonable agreement for the validation period, with an RMSE of 1.2 mm.

4. The comparison was limited by the short validation period and the initial equilibrium state of the geomechanical model, suggesting a need for further investigations.

5. For a more robust comparison, a longer period of comparison/validation is required

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THANK YOU FOR YOUR ATTENTION!

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