Modeling recent uplift subsidence caused by decreased groundwater extraction and revealed by geodetic InSAR measurements in the Brussels area

In the framework of the LASUGEO project: « monitoring Land Subsidence caused by Groundwater exploitation through gEOdetic measurements »

A. Poncelet, P. Orban, P.-Y. Declerq, M. Agniel, P.Gerard, A. Dassargues

Alain.Dassargues@uliege.be

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belspo — LIÈGE université — Geological Survey of Belgium — brussels environment .brussels — ULB

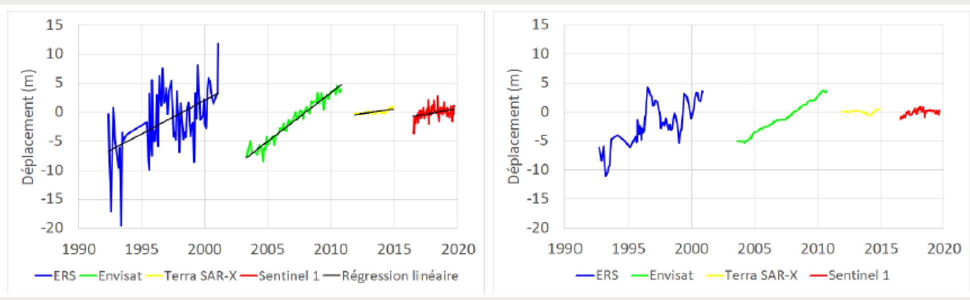
ABSTRACT

Radar interferometry (InSAR) measurements have provided recent evidence of ground movements and in particular a slight uplift in north-western areas near the center of Brussels in response to changes in groundwater pumping and drainage. Local and regional piezometric data are collected and ancient historical piezometric data are reconstructed for the deep bed-rock aquifer. The corresponding water pressures are then transmitted to 1D vertical models coupling the vertical flow (and subsequent water pressure variations) with geomechanical swelling/consolidation calculations. The discretization of the 1D model is refined in the most compressible layers to obtain an accurate transient propagation of the water pressure changes and thus a better estimation of the swelling/consolidation values. The total uplift (or subsidence) is compared to the estimations obtained from the InSAR data processing.

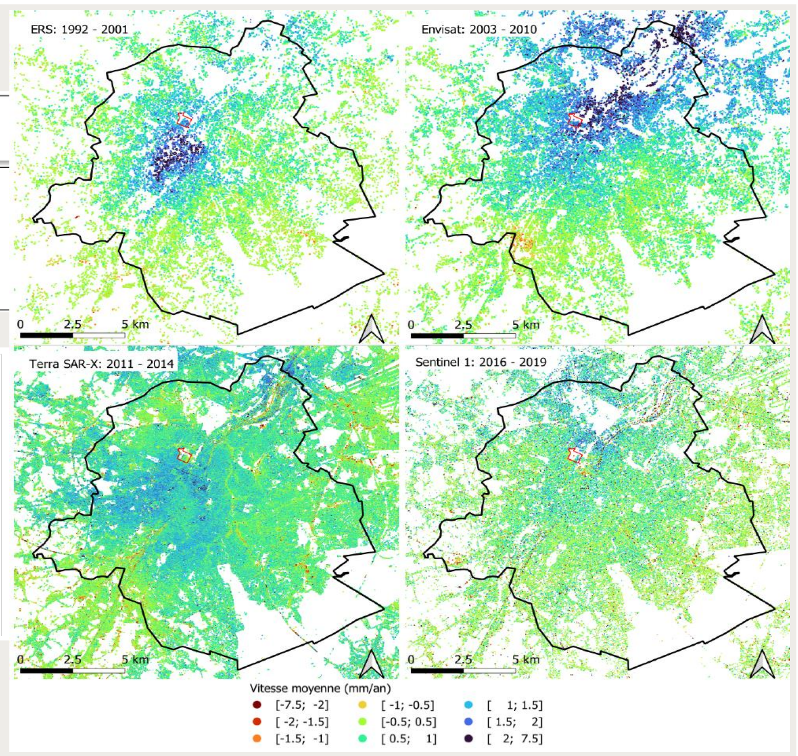
A detailed interpretation of such a comparison is not straightforward. Many factors and uncertainties can play an important role as well in the estimated values from the processing of the InSAR measurements, as in the calculated values from the coupled hydrogeological-geotechnical models.

1. InSAR measurements

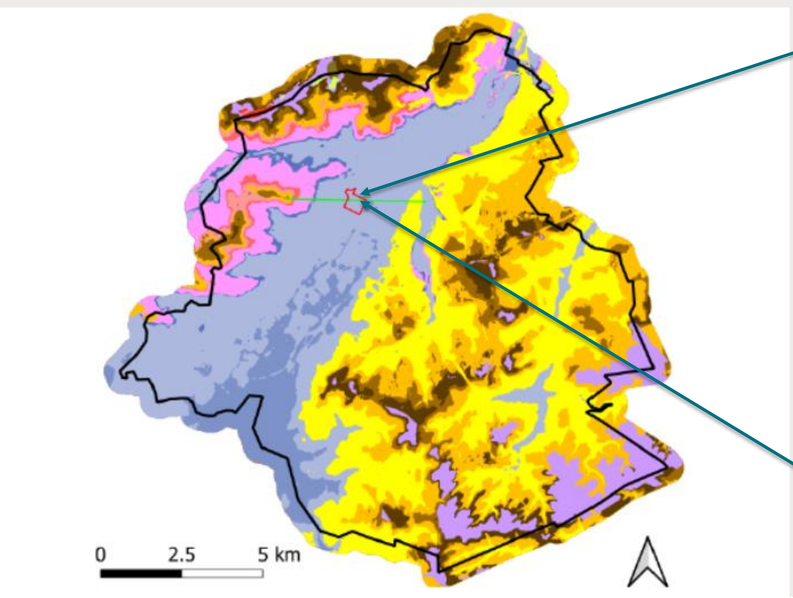
	period	select. PS number	swelling velocity mm/y
ERS	1992 - 2001	57	1.15
Envisat	2003 - 2010	38	1.67
Terra SAR-X	2011 - 2014	437	0.32
Sentinel 1	2016 - 2019	20	0.4

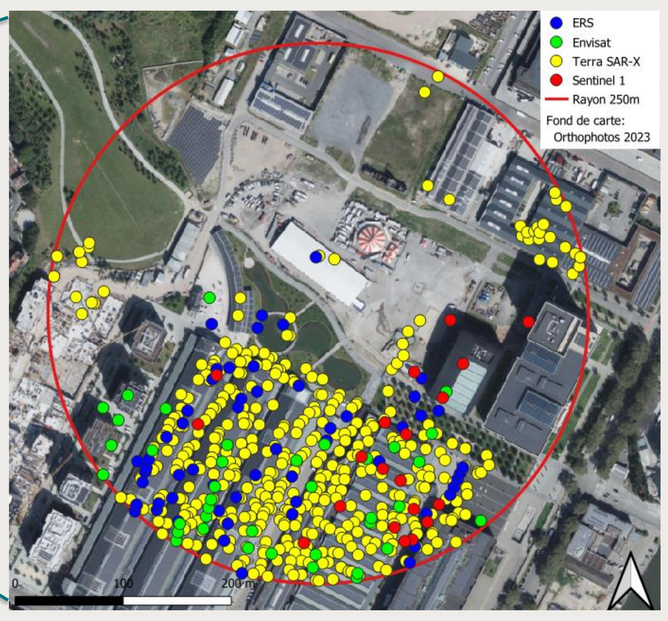


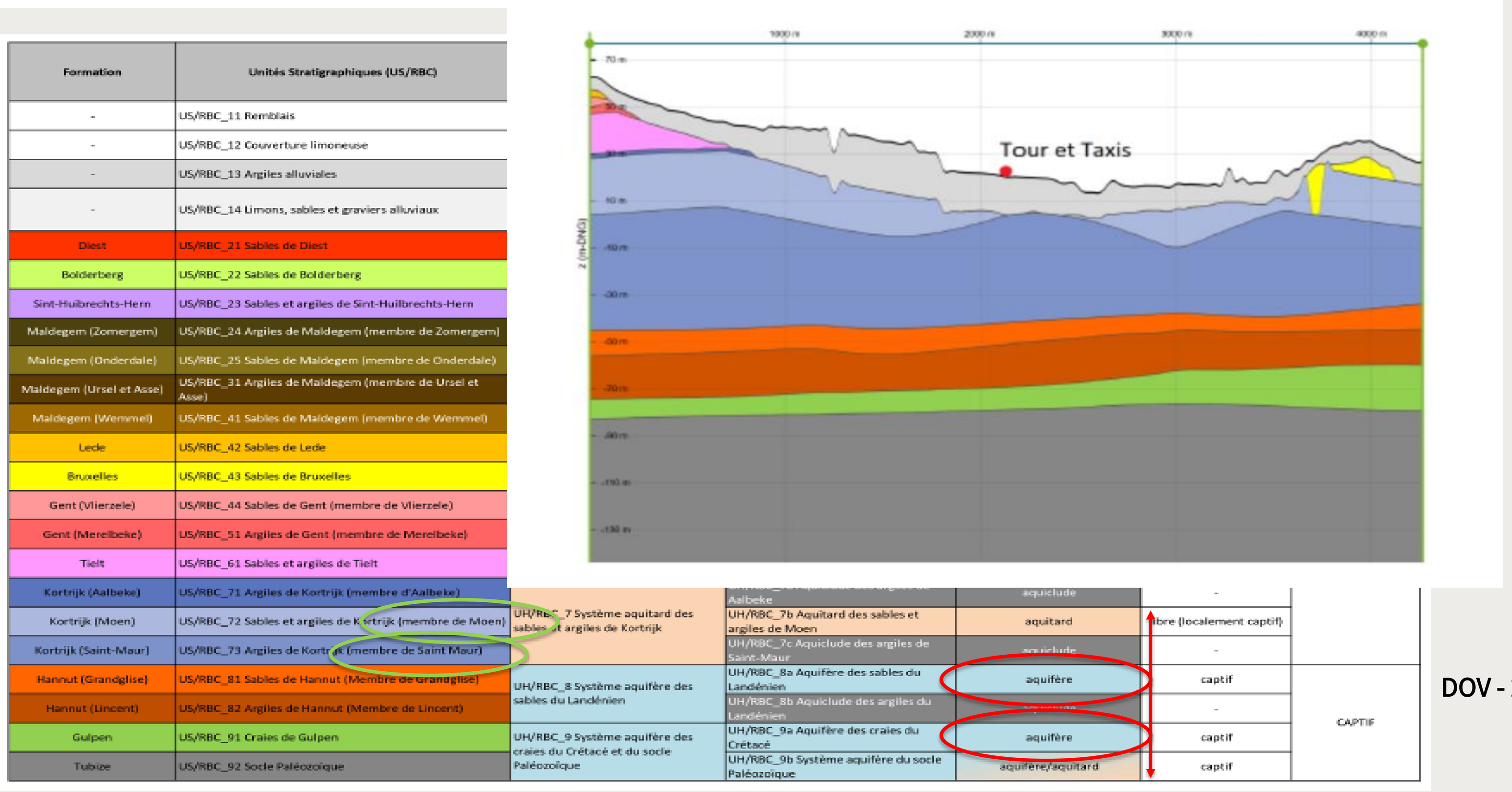
with a moving average smoothing



2. Geology & hydrogeology







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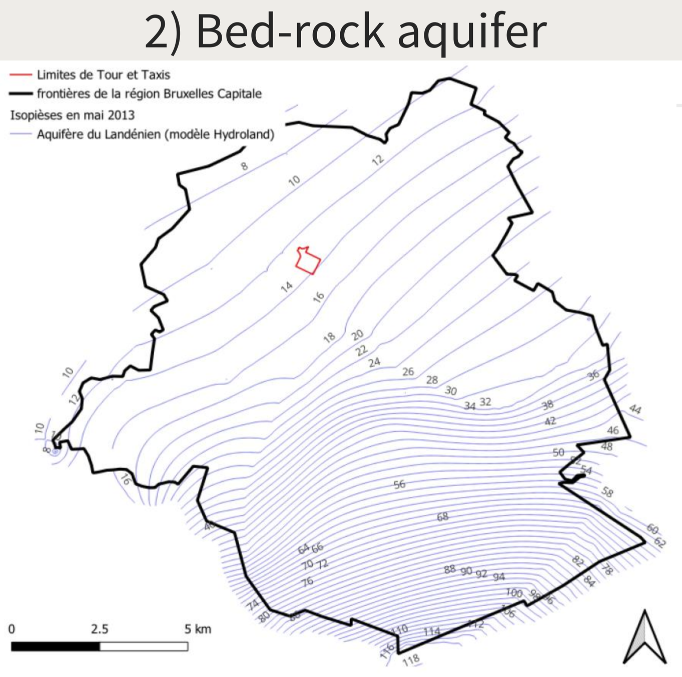
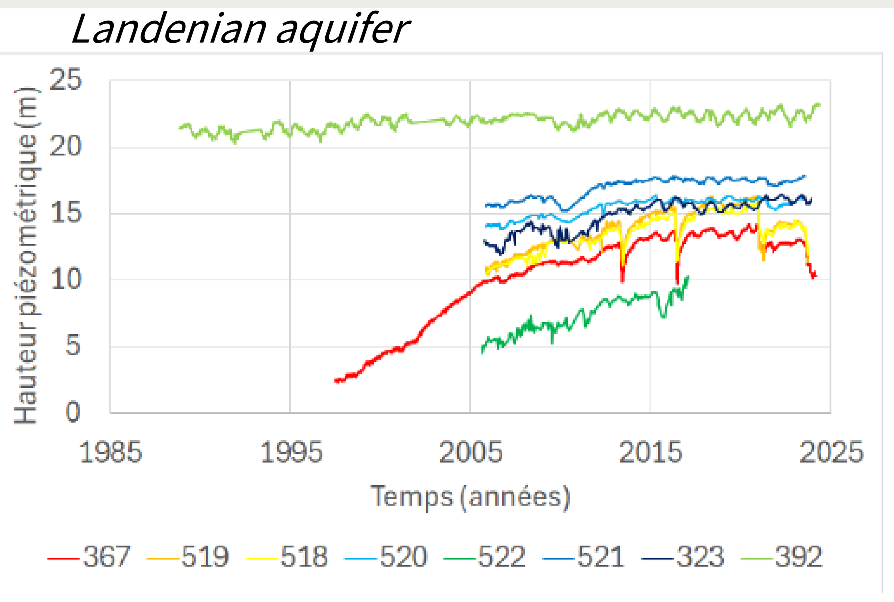
→ recent piezometric data + reconstruction of ancien local piezometric data

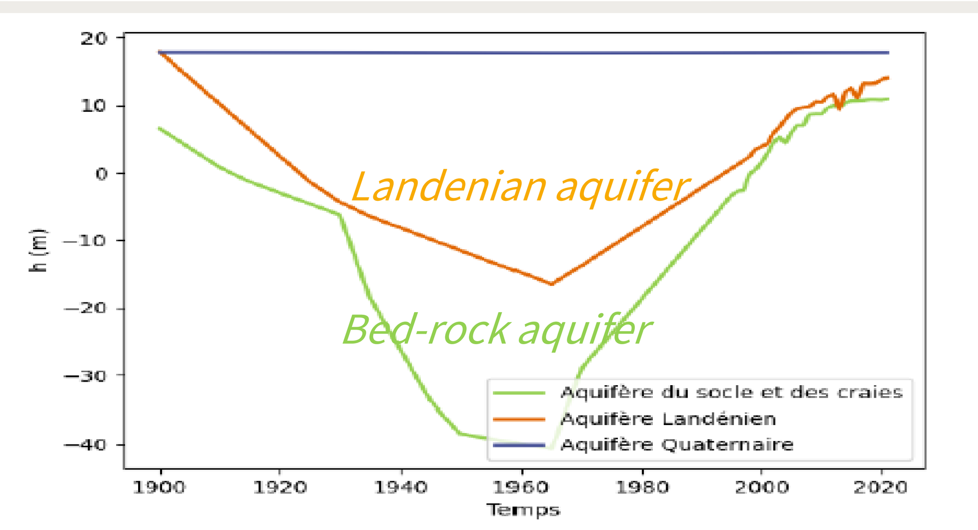
→ two main aquifers:

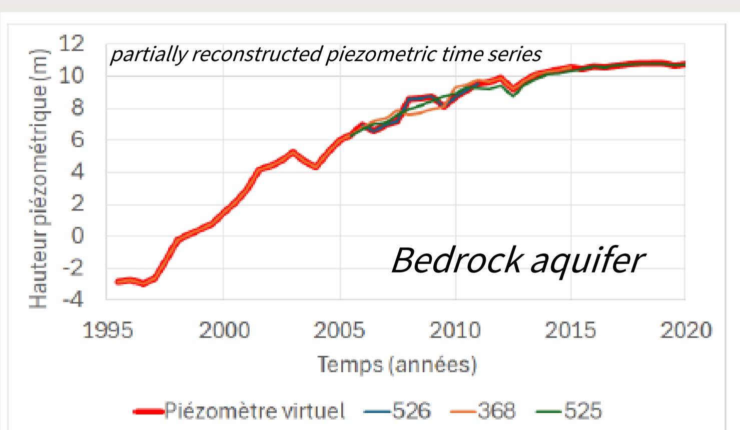
1) 'Landenian aquifer' = sand of Hannut formation

2) Bed-rock aquifer

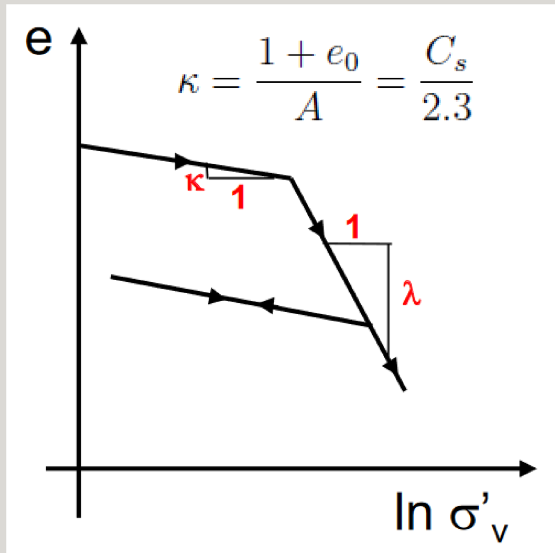








3. Geomechanical model



1D hydro-geomechanical model using the finite element method (LAGAMINE code) coupling the groundwater flow equations to the geomechanical equations.

Computed water pressures (i.e., from the calculated piezometric heads) are translated, at each time step, into effective stresses using the Terzaghi principle.

Deformations are calculated using a non-linear elastoplastic model for settlements and a non-linear elastic model for swelling.

The layers modeled are over-consolidated so that only the elastic behavior is considered.

The following elastic law is used: $\varepsilon_v = -\frac{\kappa}{1+e}\ln\left(\frac{\sigma'_1}{\sigma'_0}\right)$

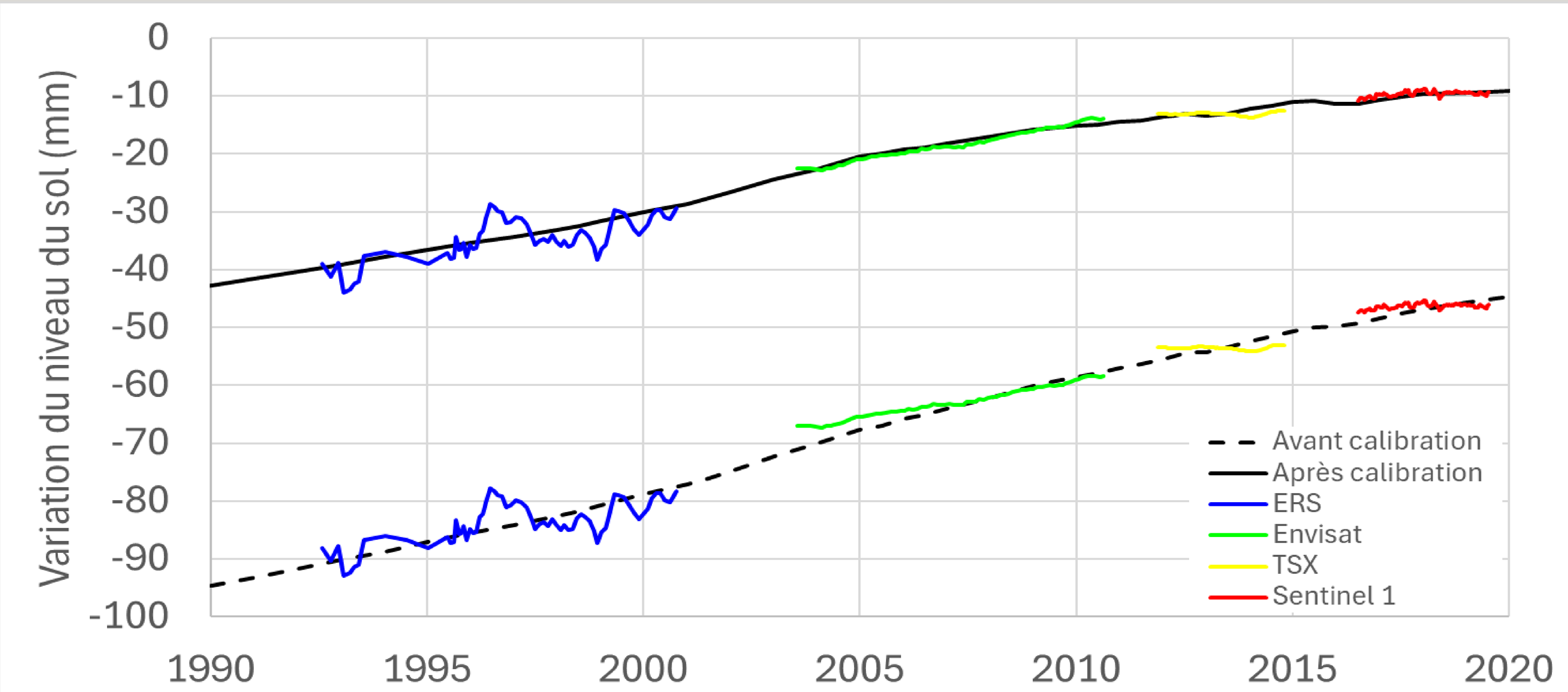
where ε_v is the relative vertical deformation, κ is the elastic compressibility factor, e is the void ratio, and σ'_1 and σ'_0 the initial and final effective stress respectively.

An initial value of $\kappa = 0.0168$ is taken for the Saint-Maur Formation (Ypresian clays) which is the harmonic mean of the different values from various studies (Poncelet, 2024, Bolle et al., 2006, Dam et al., 2009).

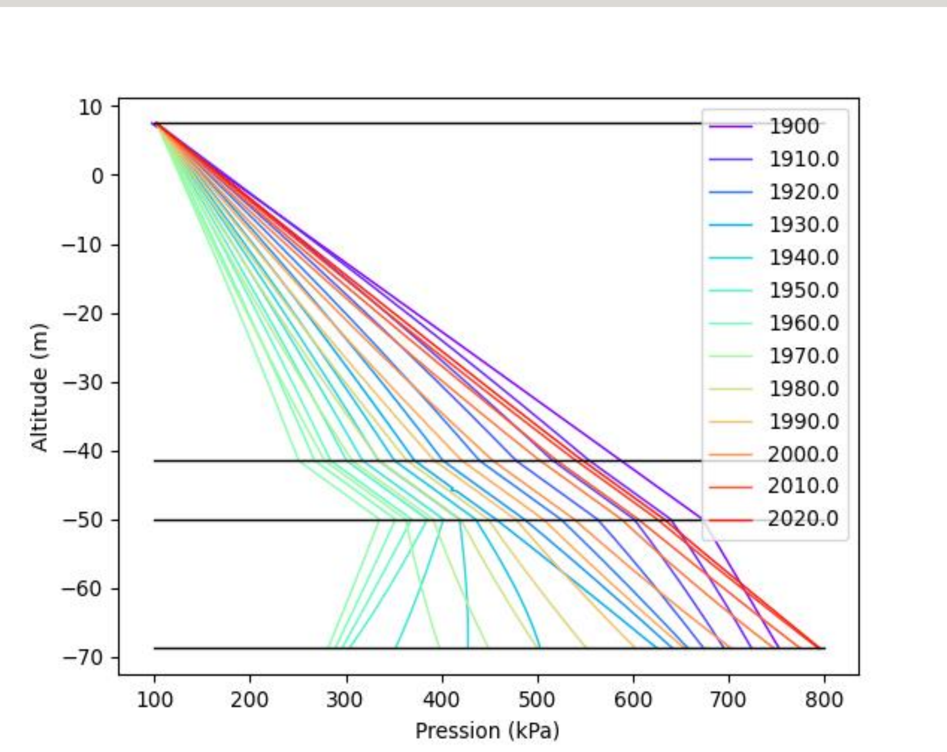
Initial values for the vertical hydraulic conductivity are taken as the geometric means from the data of the geotechnical maps (Poncelet, 2024, Dam et al., 2009).

	Thickness (m)	Number of elements	Size of elements(cm)
Ypresian aquitard	49	191	25.7
Landenian aquifer	8.5	18	47.2
Landenian aquitard	18.75	41	45.7

4. Results



Comparison between the calculated land subsidence and the time-displacement curves from InSAR measurements: before calibration (below) and after calibration (above)



Water pressure evolution in the 1D column in function of time from 1900 until 2020

5. Perspectives

→ to build a 3D groundwater flow model to be coupled to multiple 1D hydro-geomechanical models in order to simulate more accurately the actual hydrogeological conditions

→ requires a huge amount of data concerning not only the spatially distributed properties of the different layers but also a reliable data set of pumping records

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