Geomechanical modeling of the recent post-industrial uplift in Brussels and comparison with geodetic InSAR measurements

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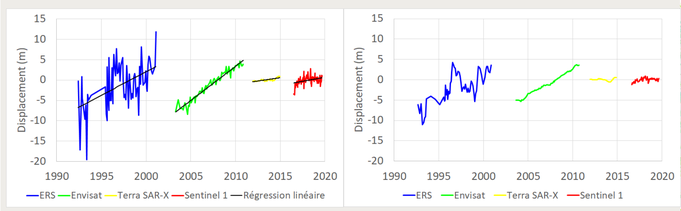
ABSTRACT

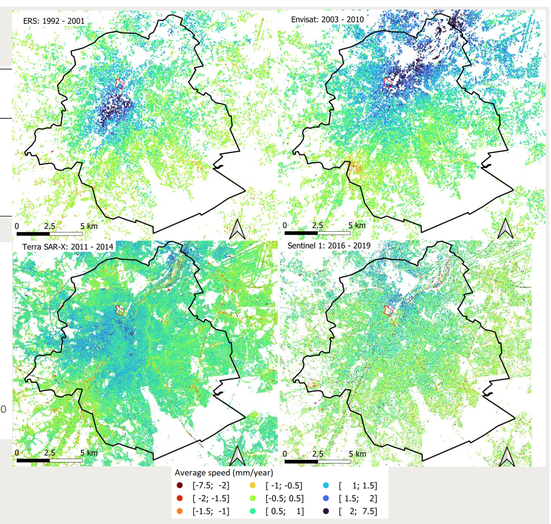
Radar interferometry (InSAR) measurements have provided recent evidence of ground movements and, in particular, a slight uplift in north-western areas near the center of Brussels (Belgium) in response to changes in groundwater pumping and drainage. Local and regional piezometric data are collected and 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.

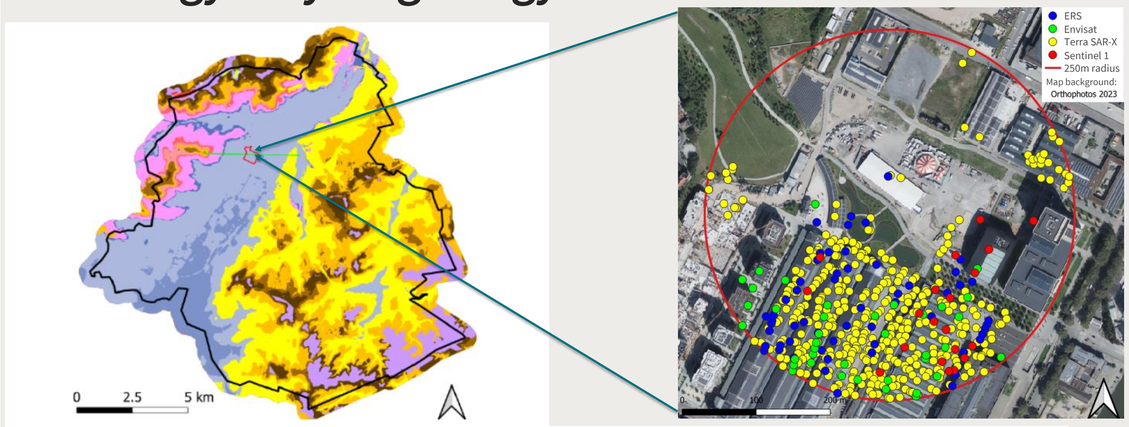
1. InSAR measurements

	period	Number of selected PSP	Average 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





2. Geology & hydrogeology



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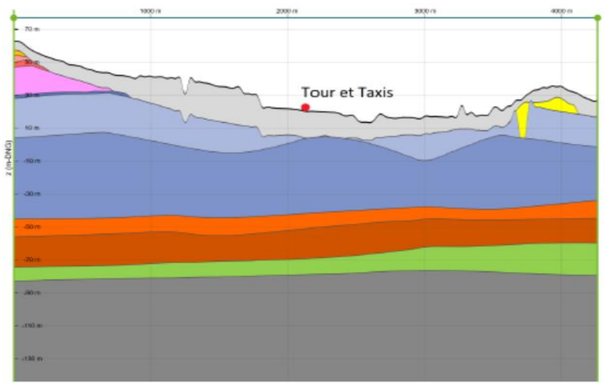
Formation	Unités Stratigraphiques (US/RBC)
-	US/RBC_11 Remblais
-	US/RBC_12 Couverture limoneuse
-	US/RBC_13 Argiles alluviales
-	US/RBC_14 Limons, sables et graviers alluviaux
Diest	US/RBC_21 Sables de Diest
Bolderberg	US/RBC_22 Sables de Bolderberg
Sint-Huibrechts-Hern	US/RBC_23 Sables et argiles de Sint-Huilbrechts-Hern
Maldegem (Zomergem)	US/RBC_24 Argiles de Maldegem (membre de Zomergem)
Maldegem (Onderdale)	US/RBC_25 Sables de Maldegem (membre de Onderdale)
Maldegem (Ursel et Asse)	US/RBC_31 Argiles de Maldegem (membre de Ursel et Asse)
Maldegem (Wemmel)	US/RBC_41 Sables de Maldegem (membre de Wemmel)
Lede	US/RBC_42 Sables de Lede
Bruxelles	US/RBC_43 Sables de Bruxelles
Gent (Vlierzele)	US/RBC_44 Sables de Gent (membre de Vlierzele)
Gent (Merelbeke)	US/RBC_51 Argiles de Gent (membre de Merelbeke)
Tielt	US/RBC_61 Sables et argiles de Tielt
Kortrijk (Aalbeke)	US/RBC_71 Argiles de Kortrijk (membre d'Aalbeke)
Kortrijk (Moen)	US/RBC_72 Sables et argiles de Kortrijk (membre de Moen)
Kortrijk (Saint-Maur)	US/RBC_73 Argiles de Kortrijk (membre de Saint Maur)
Hannut (Grandglise)	US/RBC_81 Sables de Hannut (Membre de Grandglise)
Hannut (Lincent)	US/RBC_82 Argiles de Hannut (Membre de Lincent)
Gulpen	US/RBC_91 Craies de Gulpen
Tubize	US/RBC_92 Socle Paléozoïque



		UH/RBC_7c Aquiclude des argiles de Saint-Maur	aquiclude	-
UH/RBC_7 Système aquitard des sables et argiles de Kortrijk	UH/RBC_7b Aquitard des sables et argiles de Moen	aquitard	libre (localement captif)	
UH/RBC_8 Système aquifère des sables du Landénien	UH/RBC_8a Aquifère des sables du Landénien	aquifère	captif	CAPTIF
	UH/RBC_8b Aquiclude des argiles du Landénien	aquiclude	-	
UH/RBC_9 Système aquifère des craies du Crétacé et du socle Paléozoïque	UH/RBC_9a Aquifère des craies du Crétacé	aquifère	captif	
	UH/RBC_9b Système aquifère du socle Paléozoïque	aquifère/aquitard	captif	

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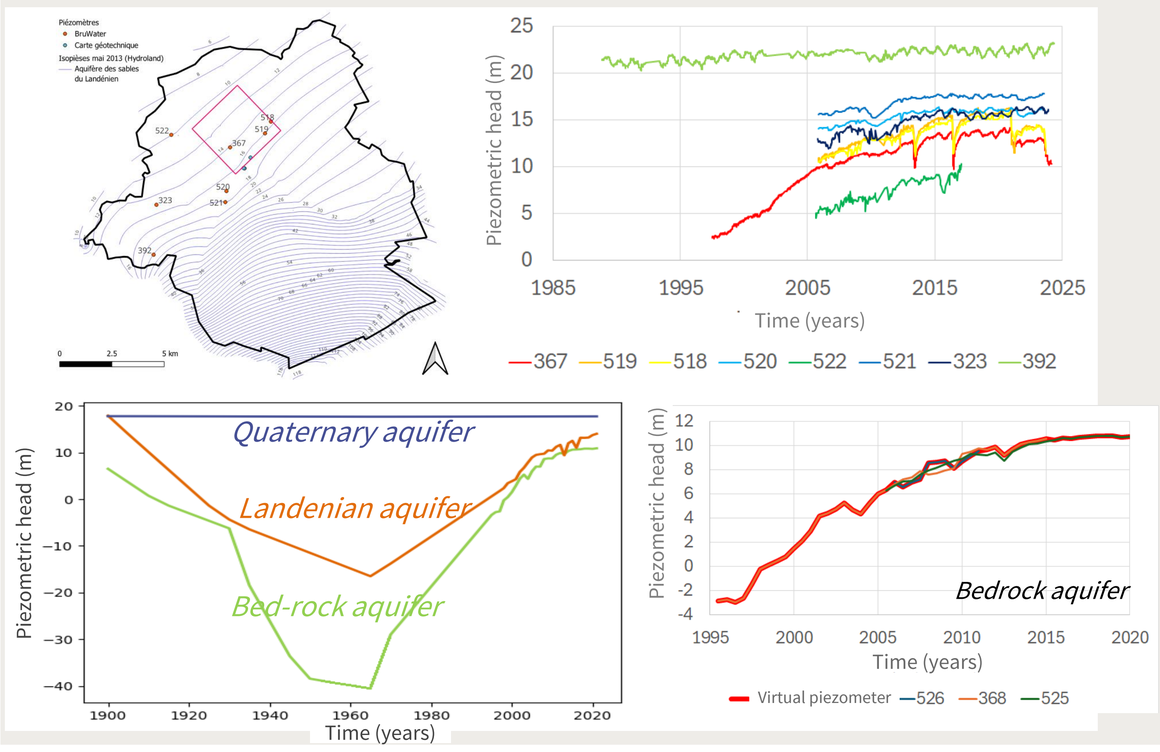
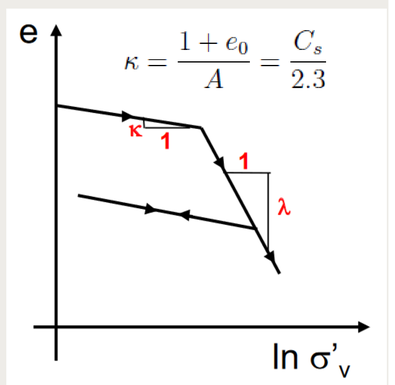
- Two main aquifers:
  1)'Landenian aquifer' = sand of Hannut formation
  2) Bed-rock aquifer
- Reconstruction of the evolution (1900-2020) of groundwater levels in the two main aquifers based on recent data and discontinuous historical data



3. Hydro -Geomechanical model

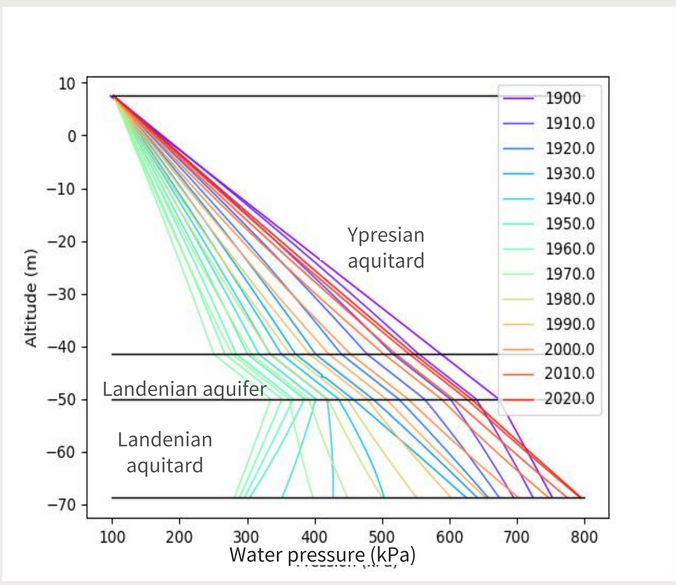


- A 1D hydro-geomechanical model using the finite element method (LAGAMINE code) coupling the groundwater flow equations to the geomechanical equations is developed
- Computed water pressures (i.e., from the calculated piezometric heads) **in each aquitards and aquifer** are translated, at each time 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.
- 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).

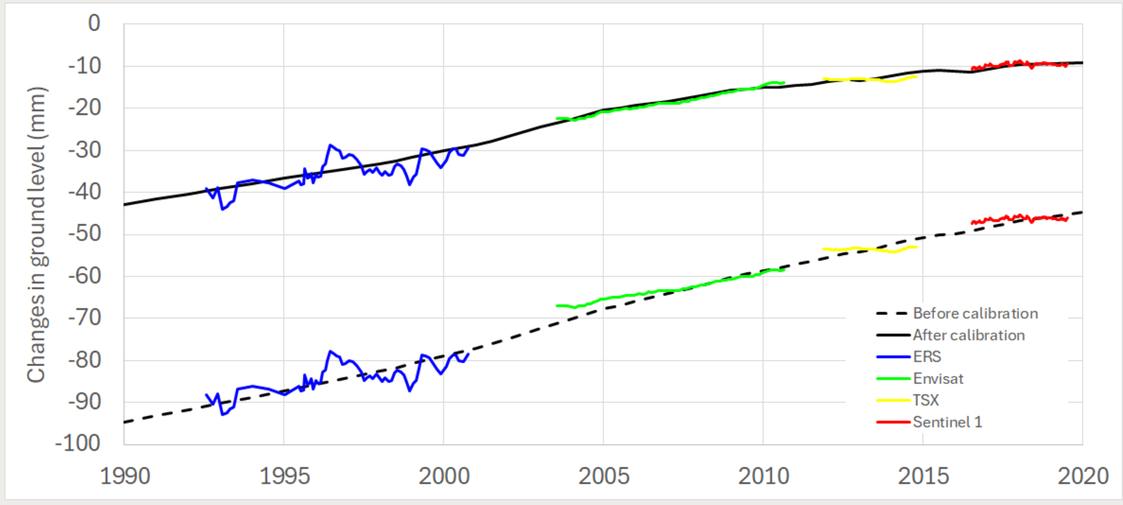
	Thickness (m)	Number of elements	Size of elements(cm)
Ypresian aquitard	49	191	25.7
Landenian aquifer	8.5	18	47.2
Landenian aquitard	18.75	41	45.7

4. Results



Based on the reconstructed groundwater levels in the aquifers, water pressure evolution in the aquifer and aquitards is computed (1D column) in function of time from 1900 until 2020.

Land compaction or swelling is then computed



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

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
- But 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

We acknowledge the support of the LASUGEO project—monitoring LAnd SUbsidence caused by Groundwater exploitation through gEOdetic measurements - LASUGEO has received funding from Brain-BE 2.0 research program – BELGIAN RESEARCH ACTION THROUGH INTERDISCIPLINARY NETWORKS (2018 -2024).