STOCHASTICAL MODELLING OF LAND SUBSIDENCE IN BOLOGNA, ITALY

AGU24 Washington, D.C. | 9–13 December 2024
WHAT'S NEXT FOR SCIENCE
EP43A-1264

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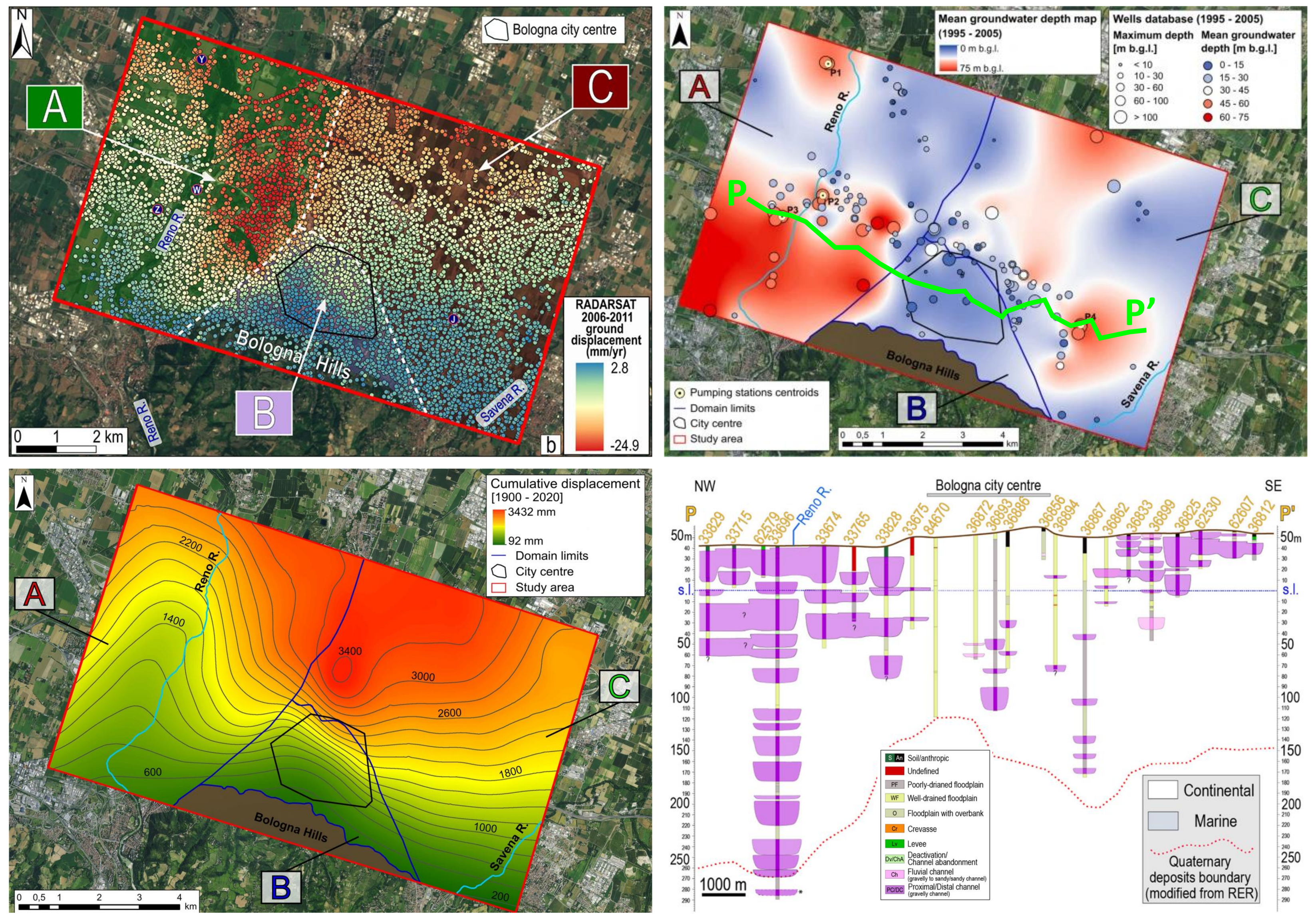
INTRODUCTION

- The city of Bologna (Italy) has experienced a huge uneven land subsidence since the 1960s mainly due to groundwater pumping.
- A complex and thick alluvial succession dominates the urban area of Bologna with a highly heterogeneous distribution of lithofacies.



(Top) Land subsidence rate (mm/year) in Bologna from 2006 to 2011 as obtained by InSAR on Radarsat images. (Bottom) Cumulative loss of land elevation (mm) in Bologna between 1900 and 2020 obtained by integration of levelling surveys and InSAR outcomes. After Giacomelli et al., (2023)

(Top) Average groundwater depth between 1995-2005 in Bologna. The location of the wells is displayed by a series of circles whose size and colour depend on their maximum depth and the computed average groundwater depth, respectively. The locations of the main four well fields are marked by light yellow circles. (Bottom) Transversal stratigraphic cross-section along the P-P' alignment shown in the top. After Zuccarini et al., (2023)

AIMS

- Understanding how uneven land subsidence can affect safety of the urban environment (urban stability and river flooding) is of paramount importance
- The lithofacies and soil properties responsible for the uneven LS measured by InSAR are challenging to be interpreted by GW flow and geomechanical models based on traditionally-based deterministic approaches

original probabilistic framework

Multizone simulations of 3-D alluvial fan structures ⟷ Data assimilation of InSAR data to constrain mechanical properties of lithofacies

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

STOCHASTIC HYDROFACIES

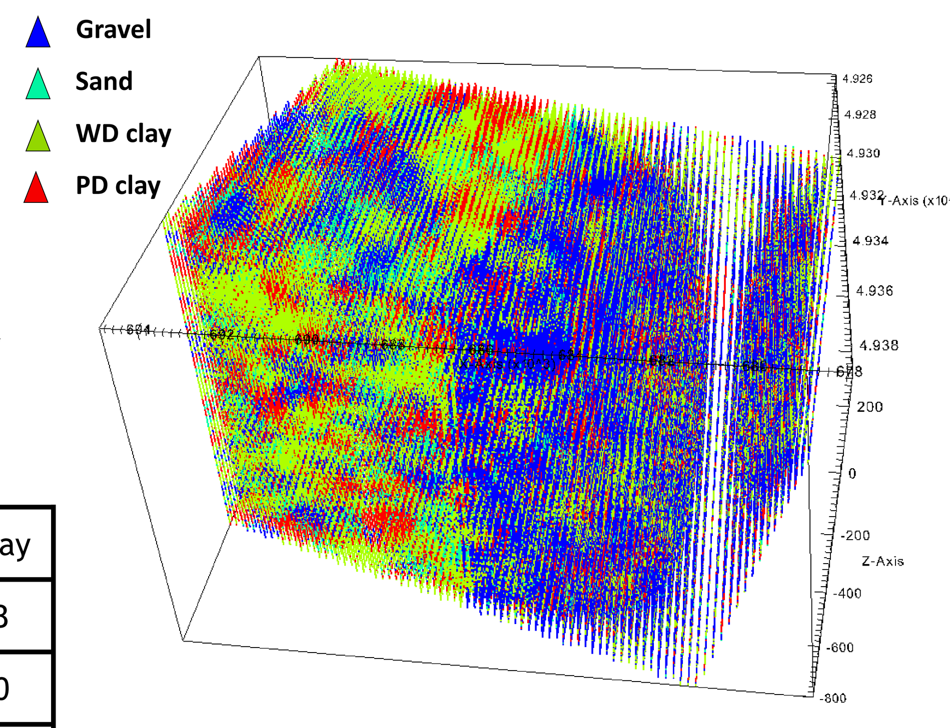
- The heterogeneity of Bologna's sedimentary aquifer system was simulated using a multizone transition probability model (**GEOST**).
- Statistical properties of the stratigraphy and borehole indicator data were preserved throughout the simulation.
- Stochastic properties derived from the stratigraphy of 176 boreholes.
- Three statistically different zones are detected main zones: Reno domain (A), Bologna area domain (B), and Savena domain (C)

The simulated area (red rectangle) around Bologna, Italy, covers 140 km², extending west to east from the Reno River to the Sevena River and south to north from the Apennine hills to the city northern suburbs. This area is divided into 3 hydrofacies zones based on the spatial lithofacies distribution.

- The stratigraphic datasets were reclassified into **four primary lithofacies**: poorly-drained fine-grained soil (PD clay), well-drained fine-grained soil (WD clay), sandy soil (sand), gravel (gravel).

	Gravel	Sand	WD clay	PD clay
Zone A	0.59	0.04	0.24	0.13
Zone B	0.10	0.10	0.50	0.30
Zone C	0.20	0.13	0.45	0.22

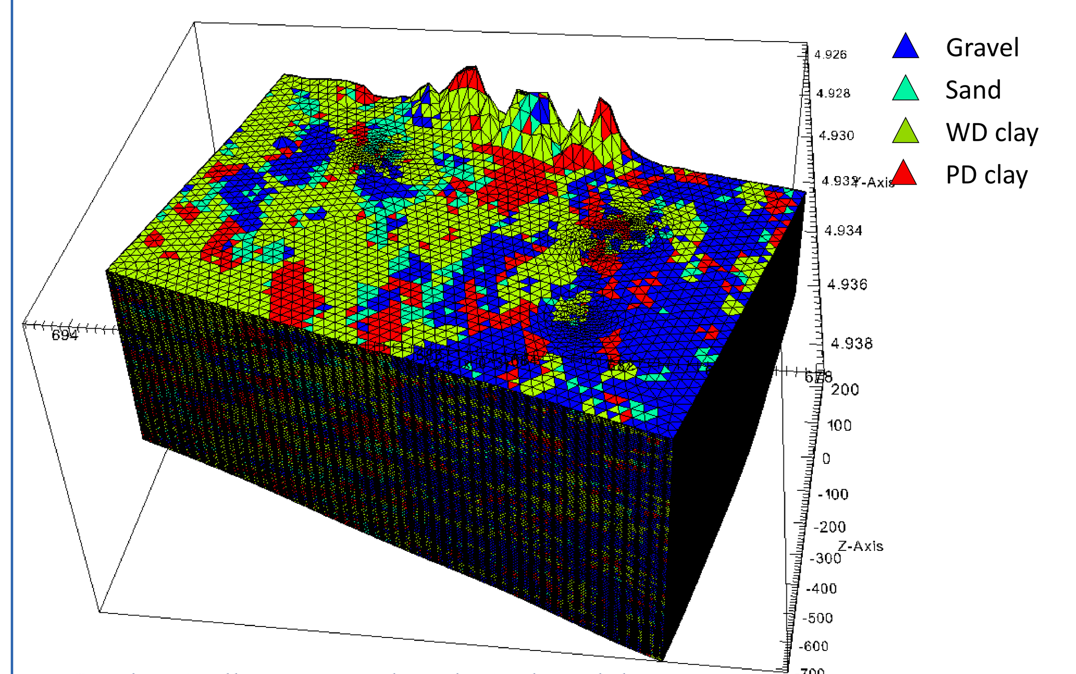
Volumetric proportions of the four lithofacies in the three subdomains based on available data.



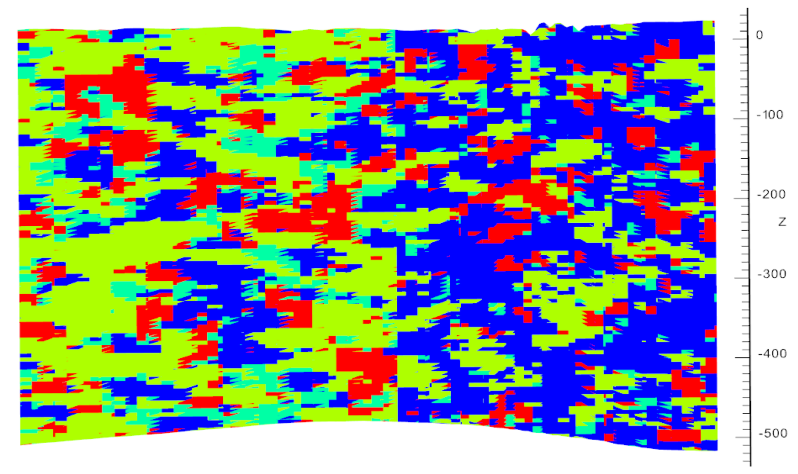
GEOST output: stochastic distribution of the four lithofacies for each zone. The 3-zone distributions are merged to reproduce the largescale variability associated to the various alluvial fan systems. The procedure developed by Zhu et al. (2016, 2020) is adopted.

3D FINITE ELEMENT DOMAIN

- A 3D FE mesh was developed. The land surface and the bottom of the Quaternary deposits are used as vertical boundaries.
- The 3D mesh totals 250'134 nodes and 1'440'672 tetrahedra, with Z ranges from 135 to -710 m above msl. The domain is subdivided vertically into 190 layers 5-m thick.



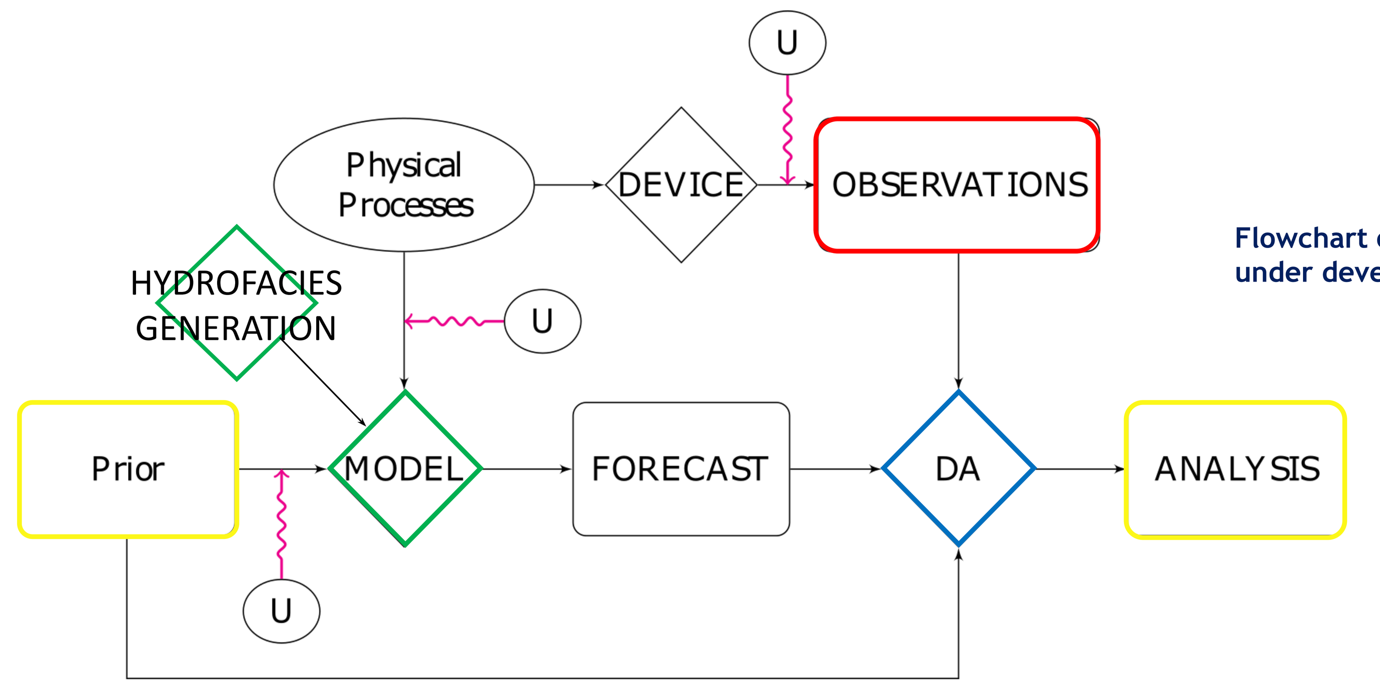
Stochastically generated geological model adapted to the Finite Element grid.



Vertical of the geological model. The heterogeneous facies geological model for the aquifer system of Bologna differs significantly from the layered type distributions typical of classical geological models.

MODELLING APPROACH & NEXT STEPS

- MonteCarlo simulation of hydrofacies distribution.
- Modelling GW flow over the period 1976-2020.
- Statistical characterization of hydrofacies compressibility by assimilating long-term piezometric records and InSAR data into a 3D geomechanical model coupled to the GW model.
- Developing scenarios over the next decades accounting for population evolution, urbanization growth and climate change.



Flowchart of the procedure under development

ACKNOWLEDGEMENTS

The project is funded by the European Union-Next Generation EU, in the framework of the Research Projects of Significant National Interest (PRIN) - National Recovery and Resilience Plan (PNRR) call 2022, and it is led by the National Research Council of Italy in Rome with the collaboration of the University School for Advanced Studies of Pavia and the University of Padua.

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