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Modeling of a Karstic Field by Application of a Cellular Automata-based Deterministic Inversion (Lez Aquifer, France)

AGU FALL MEETING
San Francisco | 12-16 December 2016

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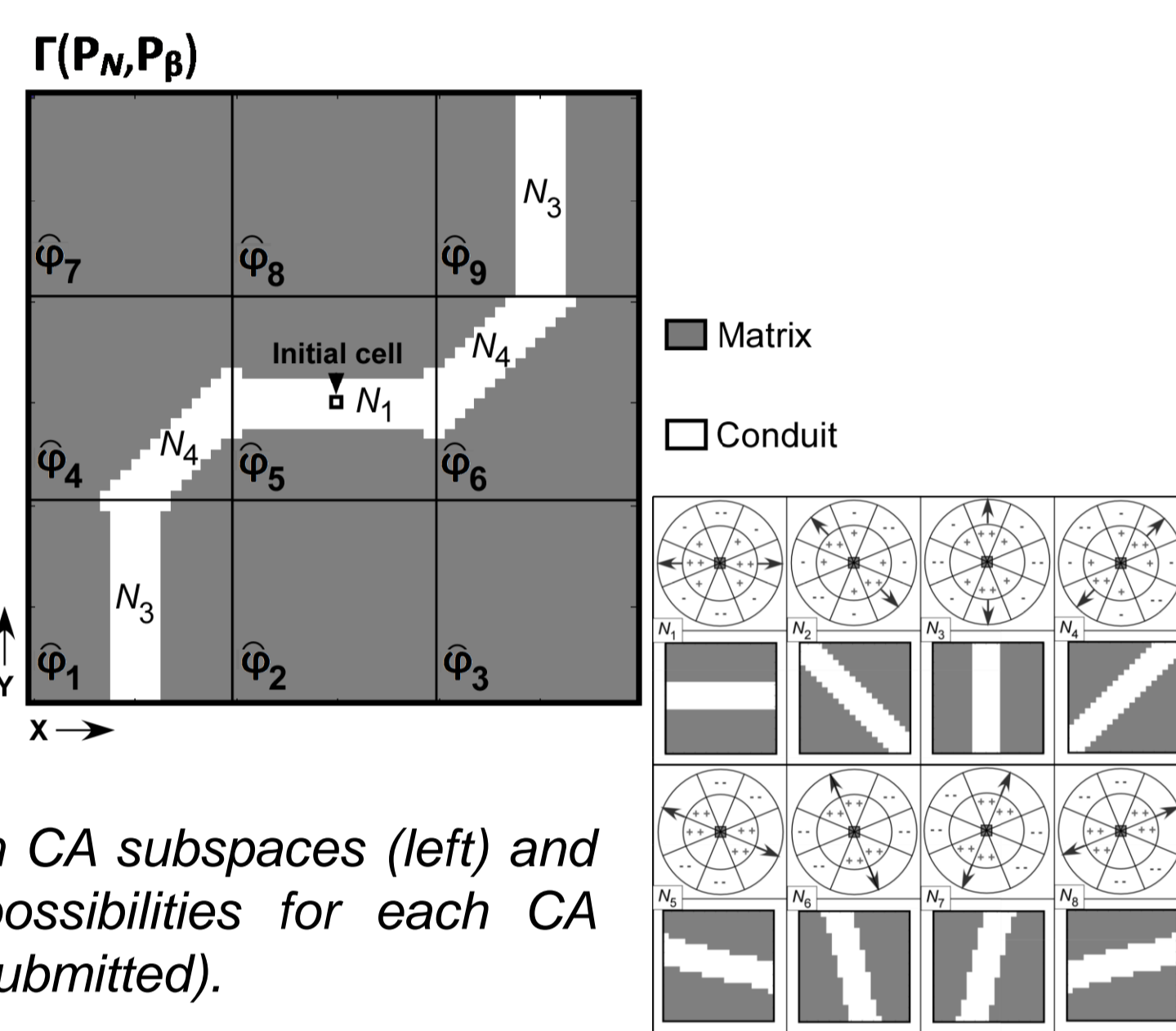
A good comprehension of the flow behaviors in a field subsurface is essential to a good groundwater management. A numerical model which is able to reproduce some observed responses (data) to a stimulation can inform on these behaviors. Therefore, an inversion process is a powerful tool to produce such models, as it will iteratively generate different models in order to minimize the differences between modeled and observed data. However for highly heterogeneous cases (as a karstic field modeling) an inversion process needs to generate realistic models (mapping these heterogeneities) and has to optimize the heterogeneity boundaries position as well as the model property values. In this context we developed the Cellular Automata-based Deterministic Inversion (CADI) method to model heterogeneous fields and we present here an application on a karstic site in Southern France.

STRUCTURAL PARAMETERIZATION OF THE MODEL

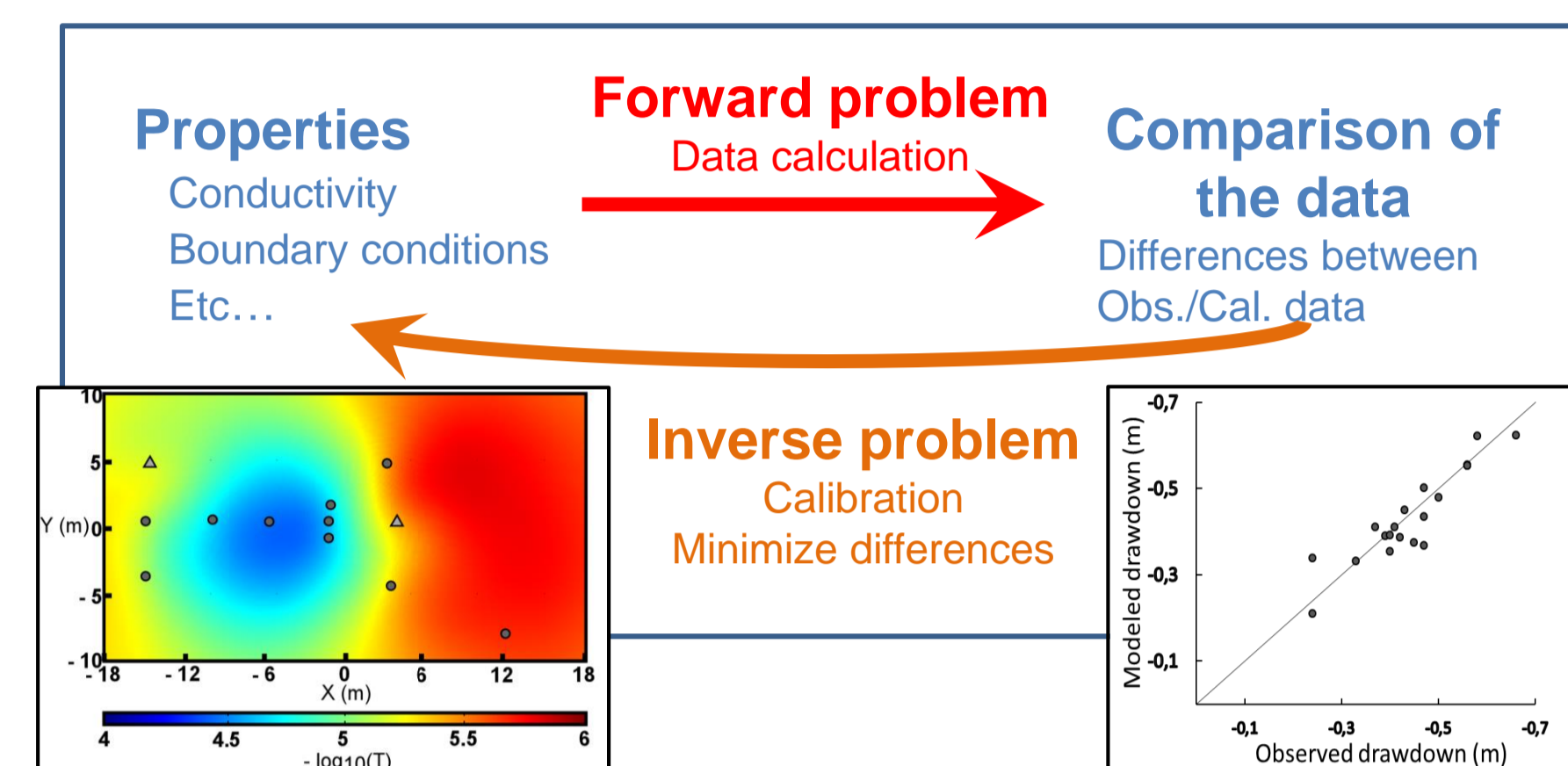
In the CADI method, an equivalent porous media model is piloted by a set of Cellular Automata (CA) subspaces. Each CA is parameterized by a structural direction (8 directions possibilities) and will distribute the property values of a model subspace in two domains (karstic conduit and matrix) in this direction. A karstic conduit in the model starts from an initial cell in a subspace and will generate among the other CA subspaces following their direction parametrization.

By modifying a CA subspace direction parameter and regenerate the model we can easily modify locally the position of the karstic network. In this way we can optimize the karstic network geometry to reproduce a set of observed data.

► A model in the CADI method partitioned in CA subspaces (left) and the 8 different direction parameterization possibilities for each CA subspace of the model (right) (Fischer et al, submitted).



INVERSE PROBLEM AND MODEL OPTIMIZATION



◀ Schema of the iterative process led during an inversion. The forward problem calculates data from a model of properties and the inverse problem modifies these properties values in order to minimize the differences between calculated and observed data (Fischer et al, 2016).

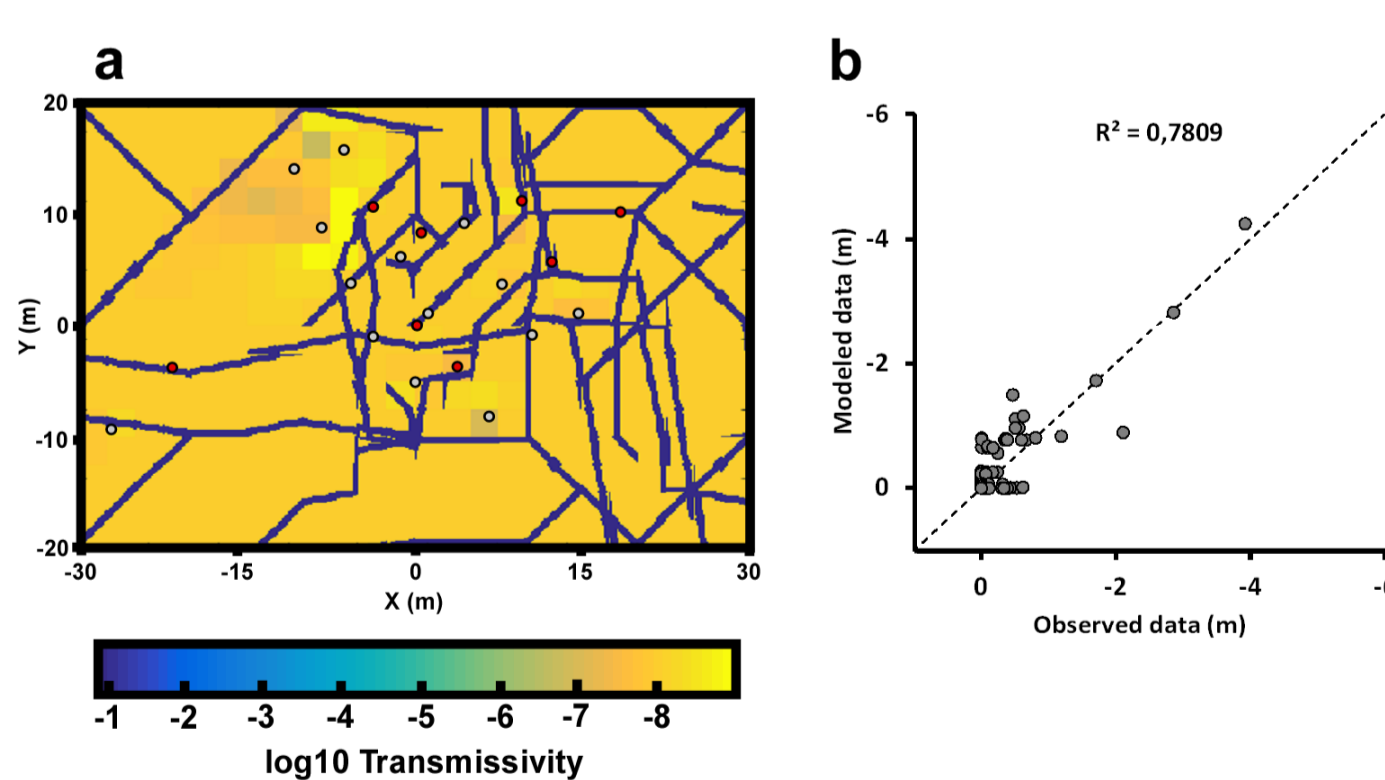
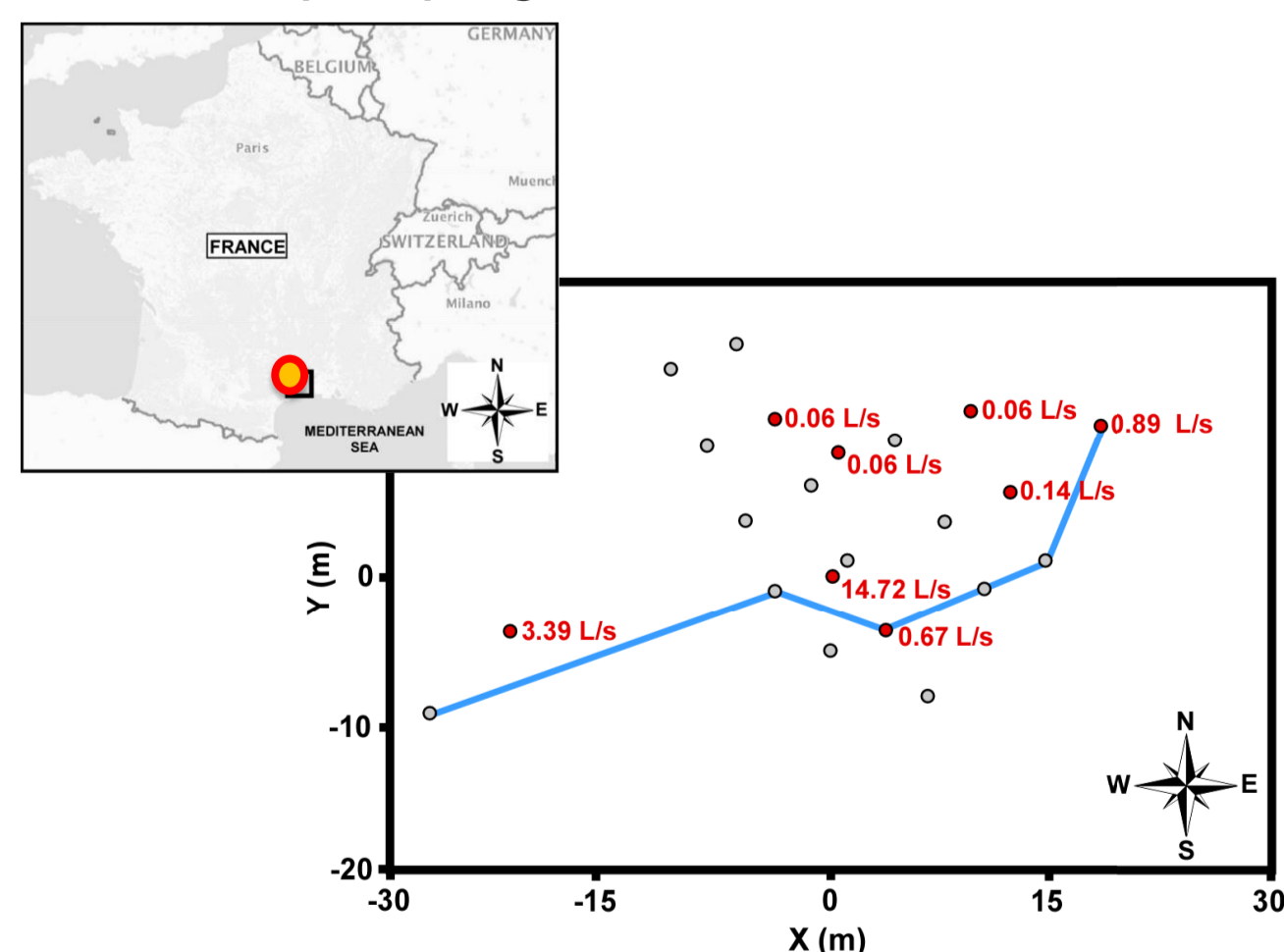
The inversion process in the CADI method is deterministic, it will generate models which improve at each iteration the minimization of the difference between observed and modeled data. Starting from an initial model with a simple karstic network, it will first optimize the network geometry until it cannot improve the reproduction of the data. Then, from the inverted network structure it will optimize the matrix and conduits equivalent transmissivity values in each CA subspace to produce the final model. From this final model, uncertainty map on the network geometry and on the transmissivity values toward the data can be produced to localize the parts of the model which are less probable.

APPLICATION ON AN EXPERIMENTAL KARSTIC SITE (LEZ AQUIFER, FRANCE)

The Terrieu experimental site is a karstic field located in Southern France in the Lez aquifer. It is a research pilot site for the French network SO Karst. The Terrieu site extends over an area of 2,400 m² and its field is composed of fractured limestones. The main flows follow a sloped bedding plan in a fault on which a karstic network has generated. The field has been investigated by a hydraulic tomography on 8 alternate pumping boreholes associated to 21 drawdowns measurement points. These drawdowns represent the observed data we have used for the CADI modeling application. The modeling was led in 2-D and represents the karstic network existing along the transmissive bedding plan.

The inversion started with a simple initial model structure (2 unidirectional conduits oriented NE-SW and NW-SE) and produced the model shown below.

▼ Localization of the Lez aquifer (left) and map of the boreholes positioning (right). The pumping points are indicated as red dots with their pumping rates.

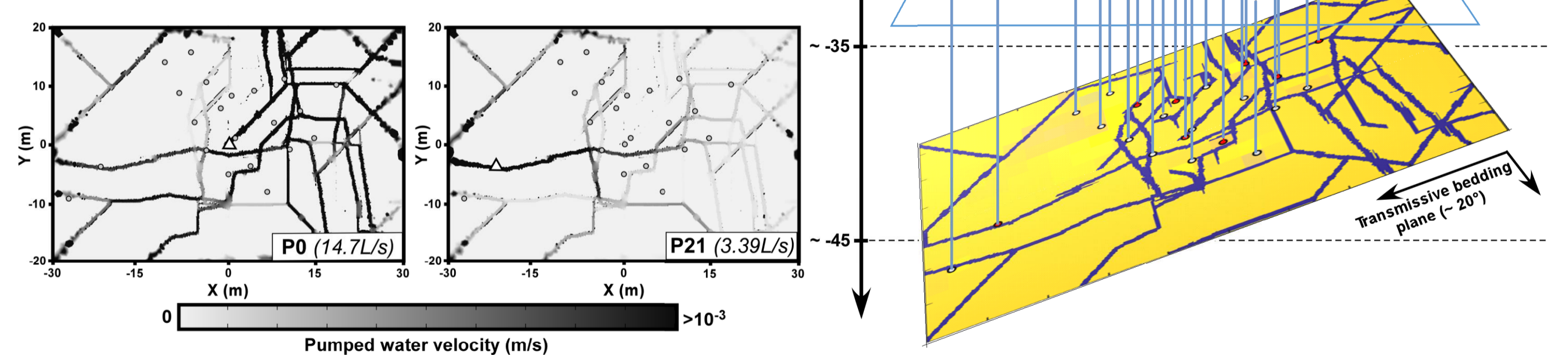


▲ Inversion result model (a) and the convergence produced on the data (b). We clearly distinguish in the model the conduits network (in blue, $T = 10^{-1} \text{ m}^2/\text{s}$) from the fissured matrix (in orange, $T = 10^{-8} \text{ m}^2/\text{s}$).

The result model show clearly the position of the main karstic network in the bedding plan. The thin fissures features are integrated within an equivalent low-transmissivity matrix. The modeled network reproduces some field observations (well connectivity, conduit direction seen by camera observations) which were not included in the inversion process. From this model we produced a 3-D schema of the Terrieu site characterized by a hydraulic tomography.

► Schema of a 3-D representation of the Terrieu site. The karstic network has been modeled with a CADI method on a 2-D bedding plan.

▼ Maps of flow velocities for a pumping in two boreholes (white triangles) with different pumping rates. Main flows are in the karstic conduits.



Such a modeling permits to localize the main heterogeneities and reproduce a physically realistic behavior of karstic fields with the flows mainly distributed in the karstic conduits. It permits to produce flow maps (particle tracing, flow velocities, drawdowns) very useful for a better understanding of the field responses on different stimulations and, thus, for a better water management.

- Fischer, Jardani, Soueid Ahmed, Abbas, Wang, Jourde, Lecoq. 2016. Application of large-scale inversion algorithms to hydraulic tomography in an alluvial aquifer. *Groundwater* doi:10.1111/gwat.12457.
- Fischer, Jardani, Wang, Jourde, Lecoq. In preparation. Application of a cellular automata-based deterministic inversion method for the distributed modeling of a karstified site (Lez aquifer, France)
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