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# Hydraulic Tomography Applications for the Characterization of Karst Structures and their Properties



EGU General Assembly 2019  
Vienna | Austria | 7-12 April 2019

Pierre FISCHER<sup>1</sup>, Xiaoguang WANG<sup>2</sup>, Abderrahim JARDANI<sup>1</sup>, Hervé JOURDE<sup>2</sup>

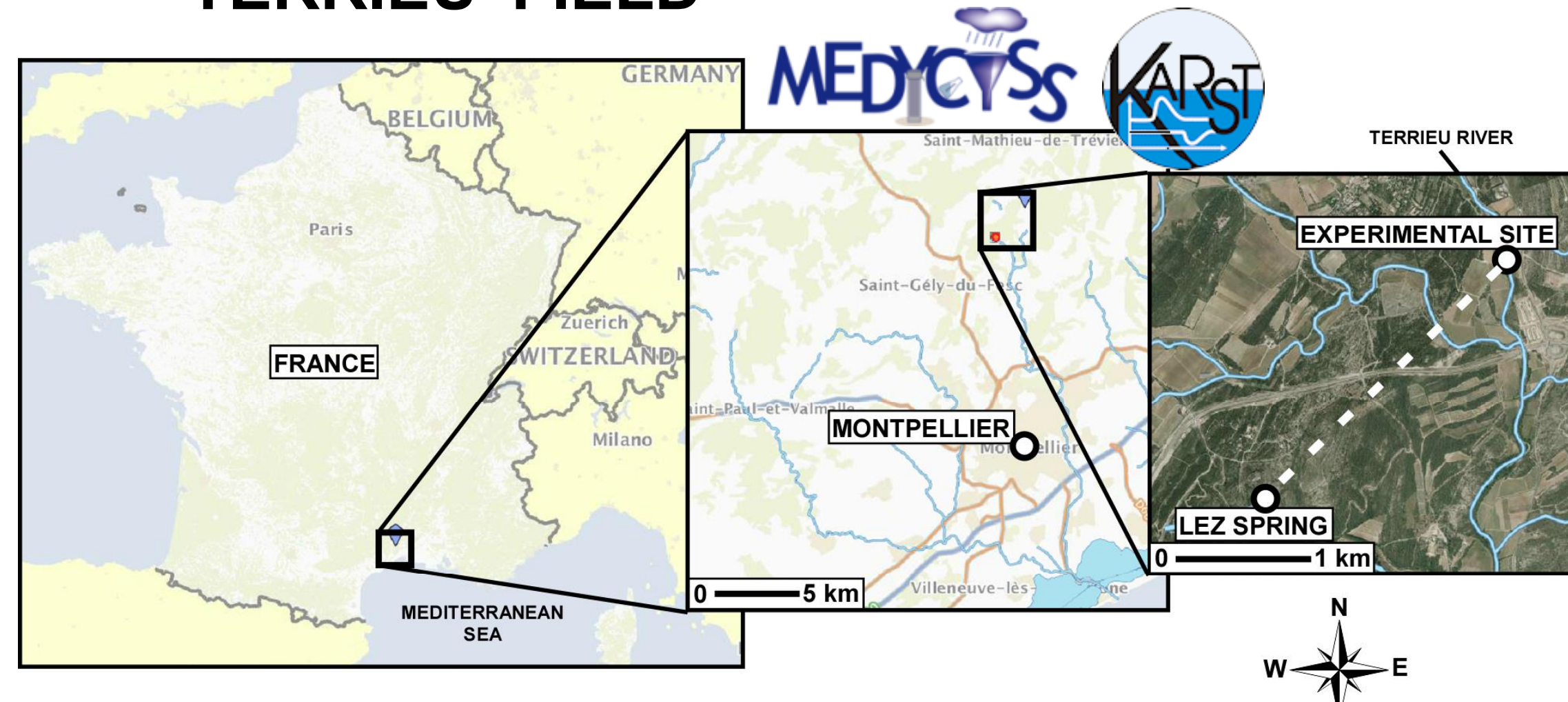
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The localization of the network of conduits in karstic fields and the characterization of their equivalent hydraulic properties represents a complex scientific problematic. Hydraulic tomography represents an efficient way to image the distribution of the field properties, but, in order to produce realistic results regarding the particularities of karstic fields, it is necessary to constrain the inversion process. We have used drawdown responses obtained from pumping investigations in the 'Terrieu' karstic field (part of the French 'SNO KARST' network), in order to test different ways to constrain the inversion process and to generate properties imagery models able to reproduce our set of responses with different complexities of network representation.

## 'TERRIEU' FIELD

► (fig.1) Localization of the 'Terrieu' karstic field in Southern France. This experimental site is part of the regional Lez aquifer.



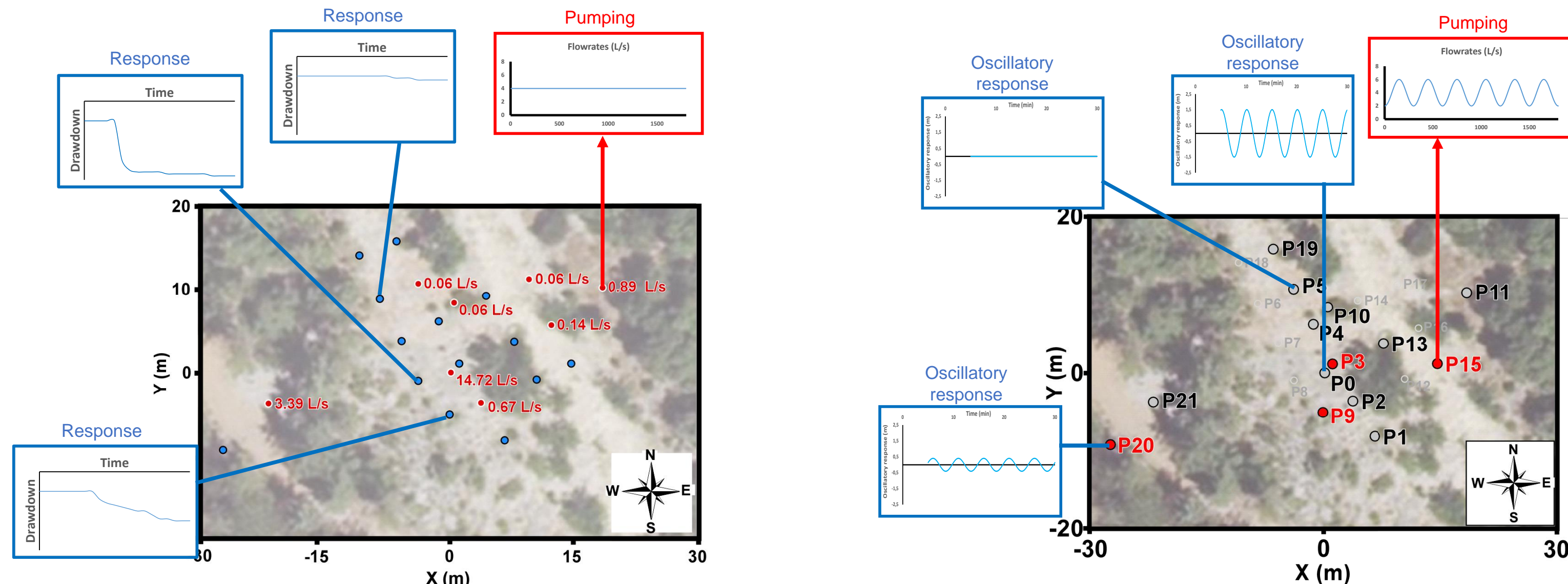
The 'Terrieu' field (fig.1) is a 60 x 40 m<sup>2</sup> site equipped with 22 boreholes to study a karst network developed

along a plane located ~40 m below the surface, at the interface between two different limestones units. This field is part of the French 'SNO KARST' and 'MEDYCYSS' networks.

## PUMPING DATA

Pumping tests were led in 2009 on 8 wells with constant pumping rates, and in 2017 on 4 wells with oscillatory pumping rates at two different periods of oscillation: 2 and 5 min (fig.2). Other boreholes were used to measure the drawdown signals during the tests. These investigations permitted to extract datasets of, respectively, 168 steady-state drawdowns and 104 amplitudes and phase shifts of oscillatory responses. These datasets were employed to perform inversions in order to characterize the distribution of the hydraulic properties within the karstic plane.

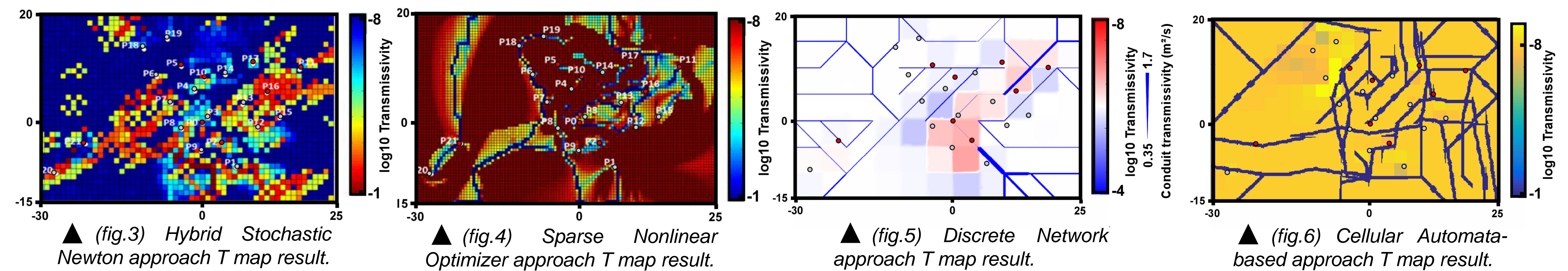
▼ (fig.2) Maps of the pumping tests of 2009 (left) and 2017 (right) and the wells used for measurements of drawdown (left) or oscillation (right) responses (red: pumping wells; red & blue/grey: measurement wells).



We thank the SNO Karst network and the region Normandy for providing their financial support to this work.

## TOMOGRAPHY RESULTS (CONSTANT-RATE PUMPING DATA)

The drawdown data obtained with the pumping tests at constant rates were employed to generate, in a 2D model, transmissivity distributions of the karstic plane, by using different inversion approaches (fig.3 to fig.6). These inversions aimed to reproduce the measured drawdown data through simulations led in a steady state domain with the transmissivity models. They should also permit to interpret the localization and connections of the conduits in the generated transmissivity maps. Therefore, four inversion approaches were tested: the hybrid stochastic-Newton [3] (fig.3), the sparse nonlinear optimizer [4] (fig.4), the discrete network [in prep.] (fig.5), and the cellular automata-based [2] (fig.6). Some approaches could generate T maps with more freedom (fig.3-4), leading to better reproductions of the measurements data. The other approaches led to better visualizations of the conduits network (fig.5-6), but less performant for the reproduction of the smallest drawdowns from the dataset, probably more related to fissures and micro-fractures in the rock than to the karst conduits. Thus, each approach presents advantages regarding what one wants to characterize in the model.



## TOMOGRAPHY RESULTS (OSCILLATORY-RATE PUMPING DATA)

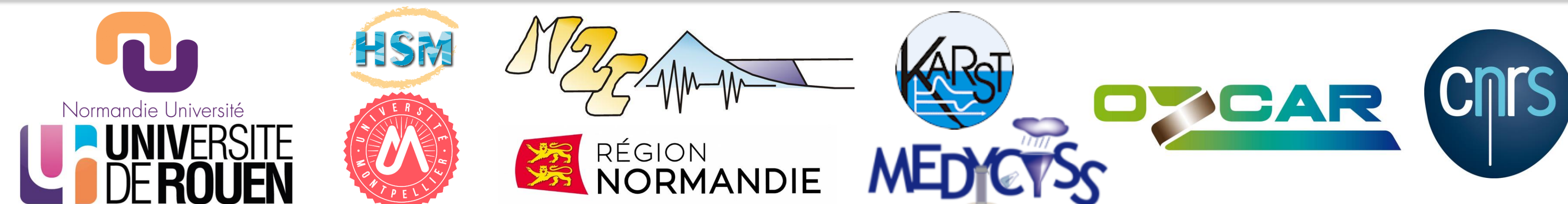
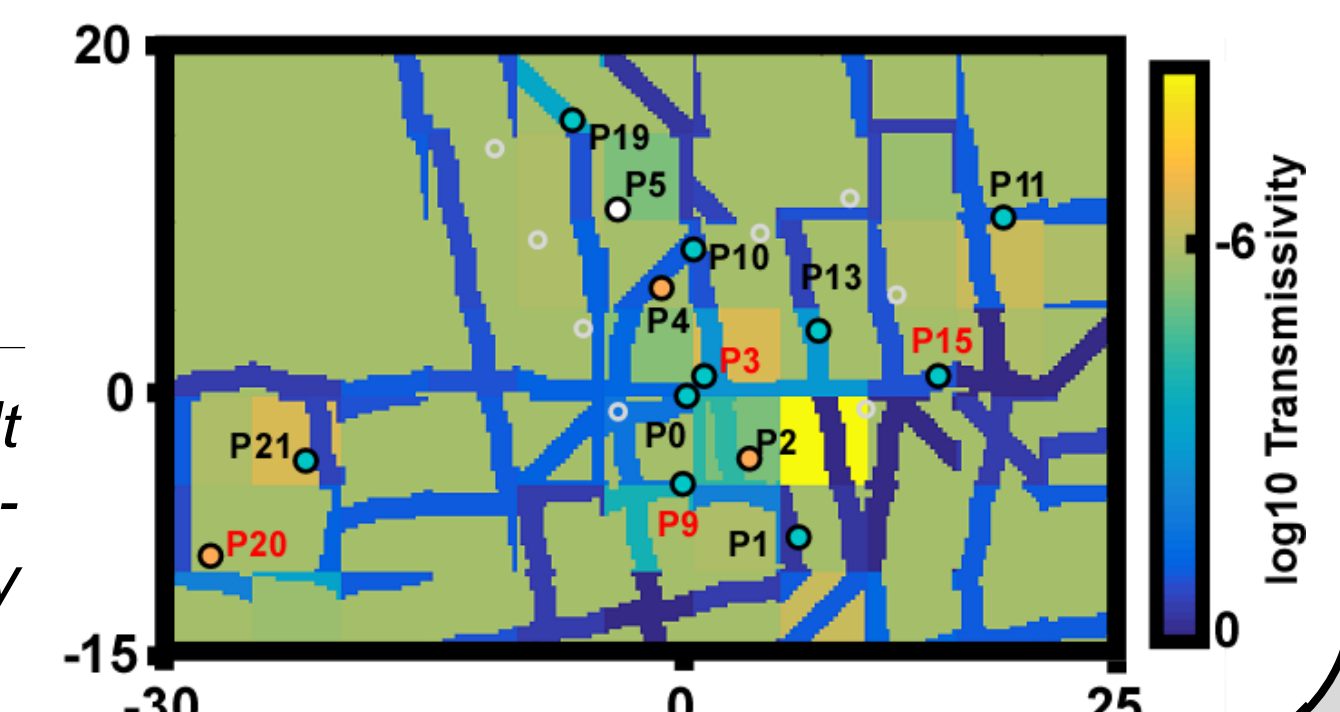
The oscillatory data (in term of amplitude decay and phase shift) obtained with the pumping tests at oscillatory rates were used for inversions with the cellular automata-based approach [1] (fig.7). The simulations were led in a frequency domain with T and S models. Separate inversions were performed with the data associated to each of the periods of oscillation (2 and 5 min), in order to study the information brought by different frequencies of oscillation. Globally, it appeared from the results that the lower frequency data (period 5 min) generated a more detailed map of the karst network, thus providing information on the localization of the different karst structures (conduit, fracture, and fissure). The higher frequency data

(period 2 min) generated a map with a sparser network, thus providing more specifically information on the main conduits, and their degree of connectivity with the different measurement wells of the field.

**HIGHER FREQUENCY INFORMATION :**  
Borehole connectivity to the main conduits network  
● In or close to (< 50 cm) the conduits network  
● 1 or 2 m away from the conduits network  
○ More than 2 m away from the conduits network

**LOWER FREQUENCY INFORMATION :**  
Localization of the karstic structures (conduit, fissures, fractures,...)

► (fig.7) T and connectivity map result obtained through the Cellular Automata-based approach in the frequency domain, with the oscillatory responses.



[1] Fischer, Jardani, Jourde, Cardiff, Wang, Chedeville, Lecoq. 2018. *Harmonic pumping tomography applied to image the hydraulic properties and interpret the connectivity of a karstic and fractured aquifer (Lez aquifer, France)*. *Advances in Water Resources* 119: 227-244.

[2] Fischer, Jardani, Wang, Jourde, Lecoq. 2017. *Identifying flow networks in a karstified aquifer by application of the cellular automata-based deterministic inversion method (Lez aquifer, France)*. *Water Resources Research* 53: 10508-10522.

[3] Wang, Jardani, Jourde. 2017. *A hybrid inverse method for hydraulic tomography in fractured and karstic media*. *Journal of Hydrology* 551: 29-46.

[4] Wang, Jardani, Jourde, Lonergan, Cosgrove, Gosselin, Massonnat. 2016. *Characterisation of the transmissivity field of a fractured and karstic aquifer, Southern France*. *Advances in Water Resources* 87: 106-121.