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Hydraulic characterization of the capillary fringe from responses to a periodic signal in an unconfined aquifer

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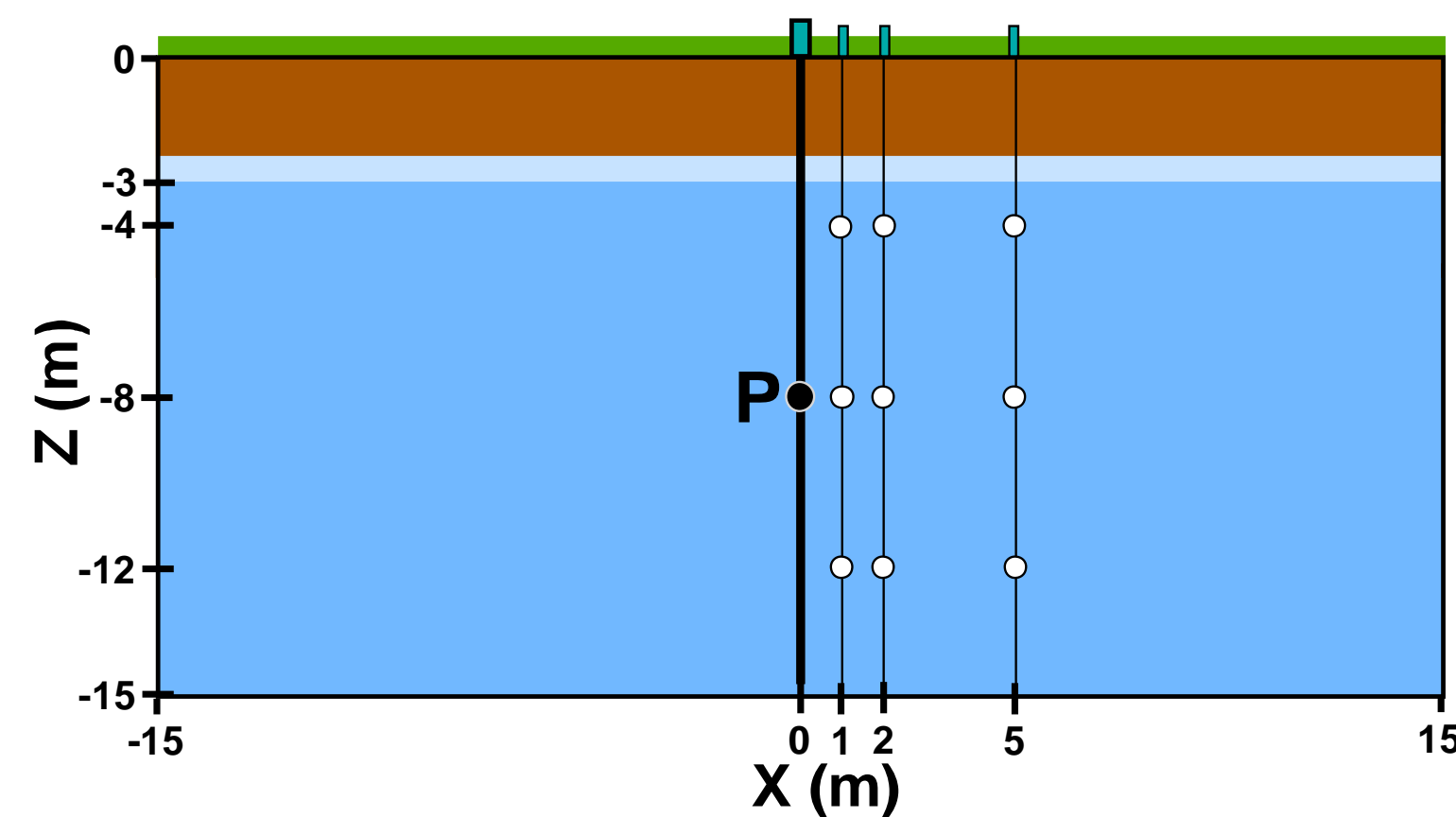
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This work ([1]) aims to study how unconfined aquifers hydraulic properties (K , S_S and the Van Genuchten coefficients α and n) influence the spatial responses to periodic signals in groundwater. Therefore we have built a numerical model in order to simulate flows associated to oscillating perturbations in a silty soil and a sandy soil. Then we have used responses associated to simple heterogeneous cases in inversions processes in order to test the imaging potential of such periodic signals for the simultaneous characterization of both saturated flows properties (K and S_S) and unsaturated flows properties (Van Genuchten coefficients) in critical zones.

THE NUMERICAL MODEL

The model is a side-view of an unconfined aquifer (fig.1). Groundwater is solicited with a localized pumping/injection periodic signal.



▲ (fig.1) Geometry of the model with the pumping point (in black) and measurement points (in white).

Flows and measured responses associated to this solicitation are simulated with the Richards formulation of the continuity equation:

$$\left(C_m(\alpha, n) + S_e(\alpha, n) S_s \right) \frac{\partial h}{\partial t} + \nabla \cdot \left(-K_r(\alpha, n) (\nabla h + \nabla z) \right) = q$$

Specific moisture capacity, Effective saturation, Specific storage, Conductivity, Porosity, Relative permeability, Oscillating signal

C_m , S_e and K_r are estimated with the Van Genuchten equations. The hydraulic properties and Van Genuchten coefficients values are chosen for a silty and sandy soil from the unsaturated soil database in [2].

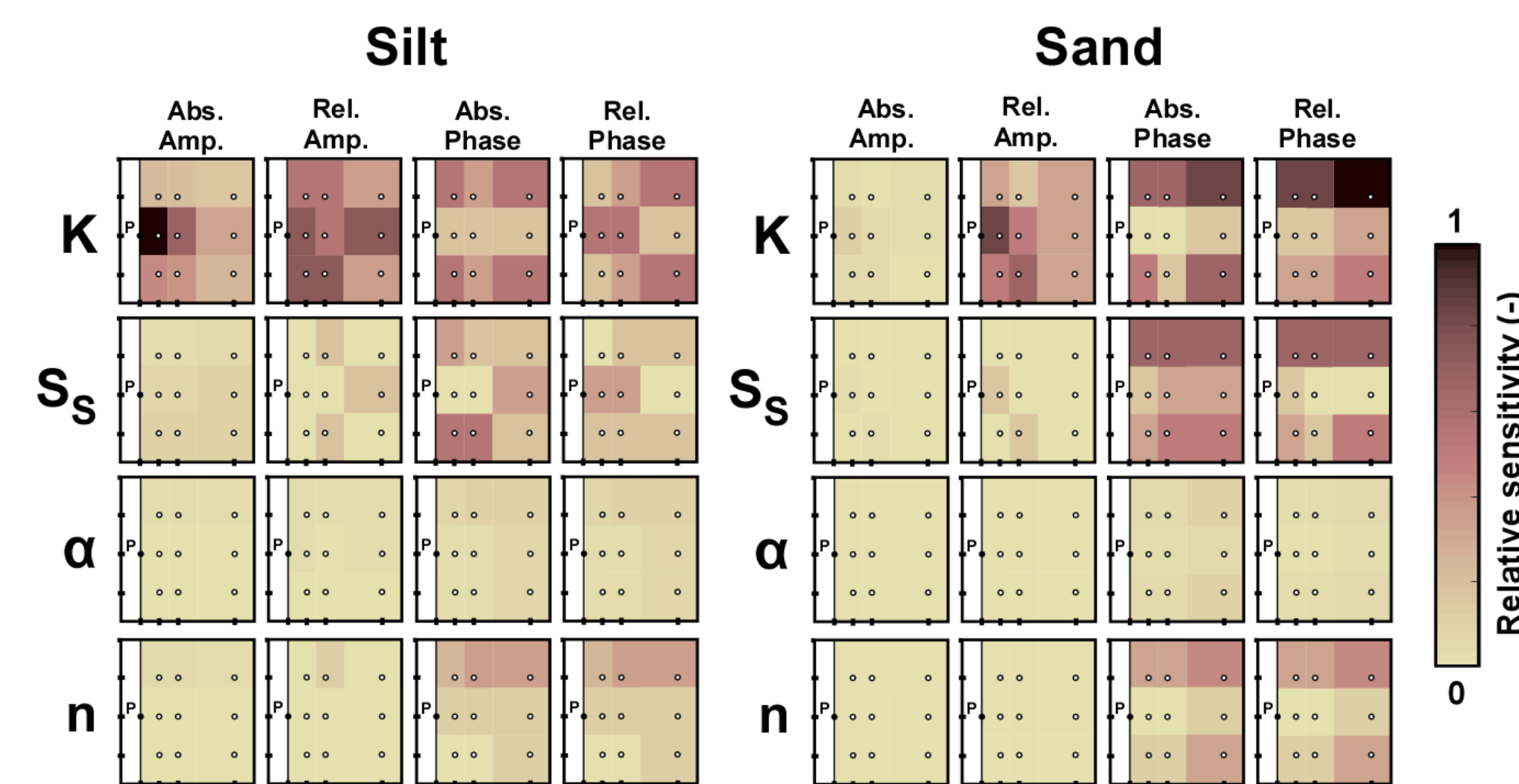
The oscillating signal is defined through its amplitude and its period (hereafter 72 L/h and 4 h respectively).

The simulated pressures are post-processed in order to study the responses at each measurement point in terms of oscillations absolute amplitudes and phases, and also relative amplitude decays and phase shifts.

SENSITIVITY TO THE HYDRAULIC PROPERTIES

We have analyzed the evolution of the measured responses when modifying the property values K , S_S , α and n in order to generate more/less drainage impacts in the two different types of soils (fig. 2). We have then performed a sensitivity analysis of the different properties toward these different responses (fig. 3).

► (fig.2) Evolution of the oscillatory responses (amplitude in blue and phase in green) when modifying the hydraulic property values in the two types of soils.

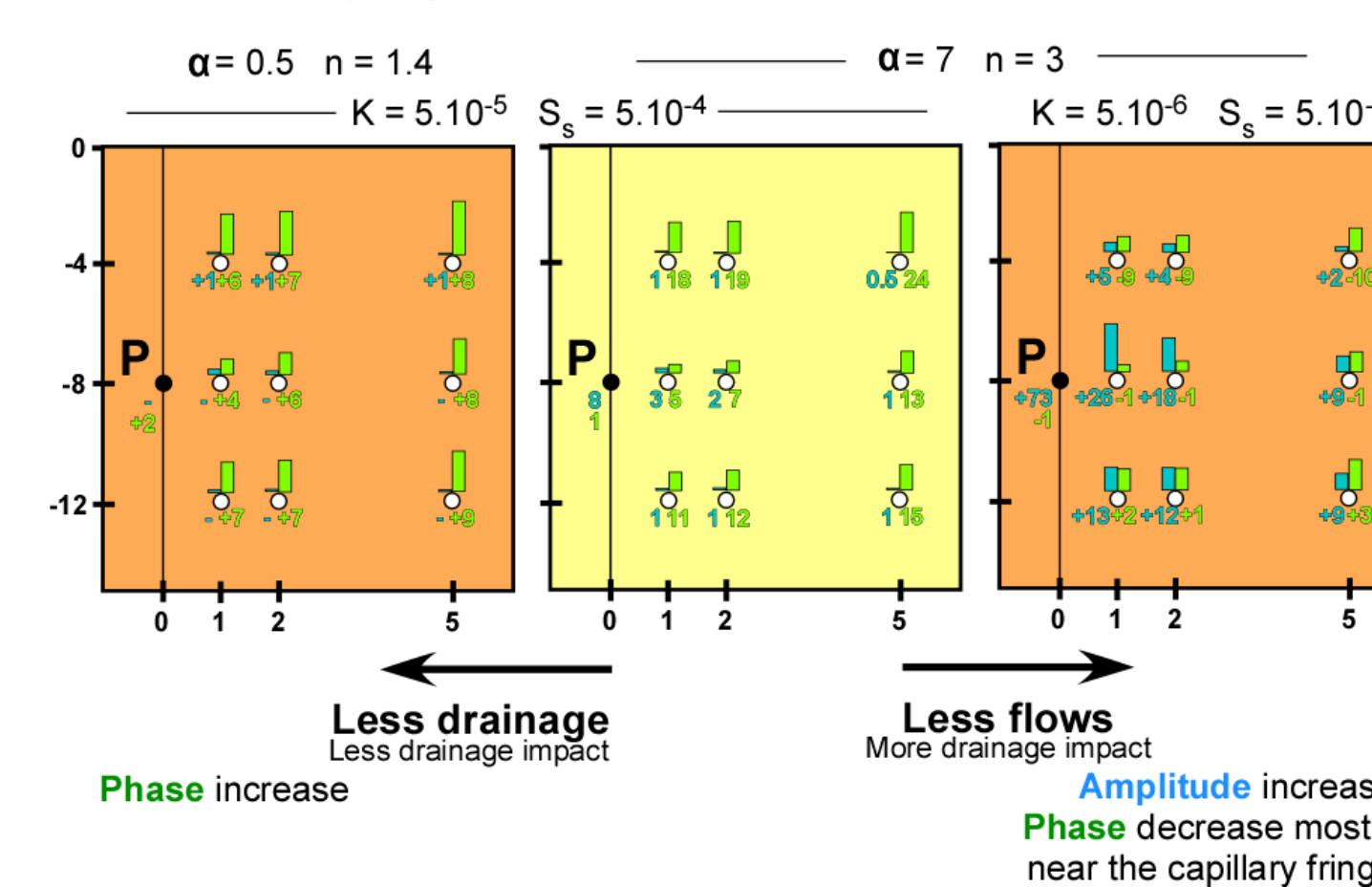
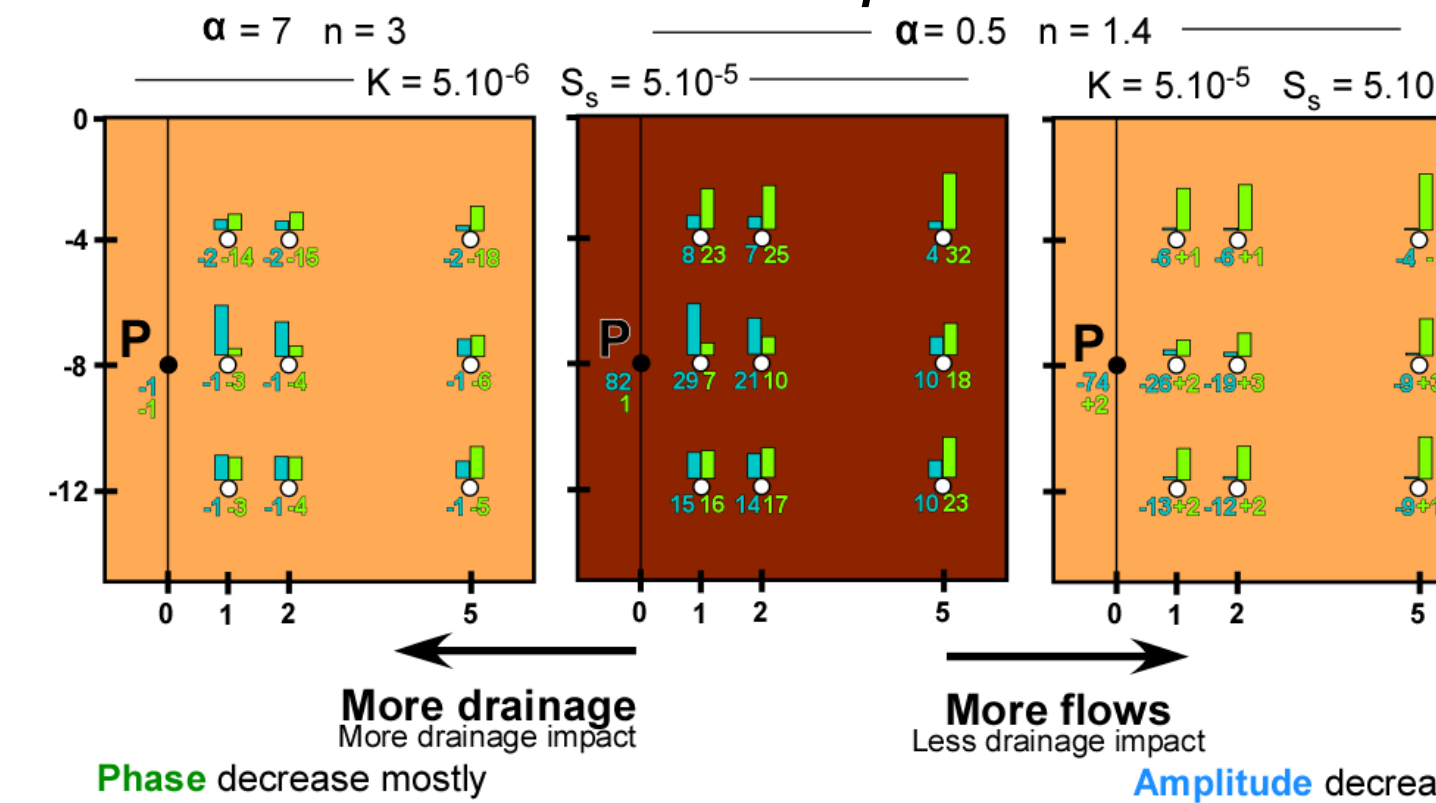


▲ (fig.3) Results of the sensitivity analysis for the two types of soils with sensitivities relativized to the maximal value.

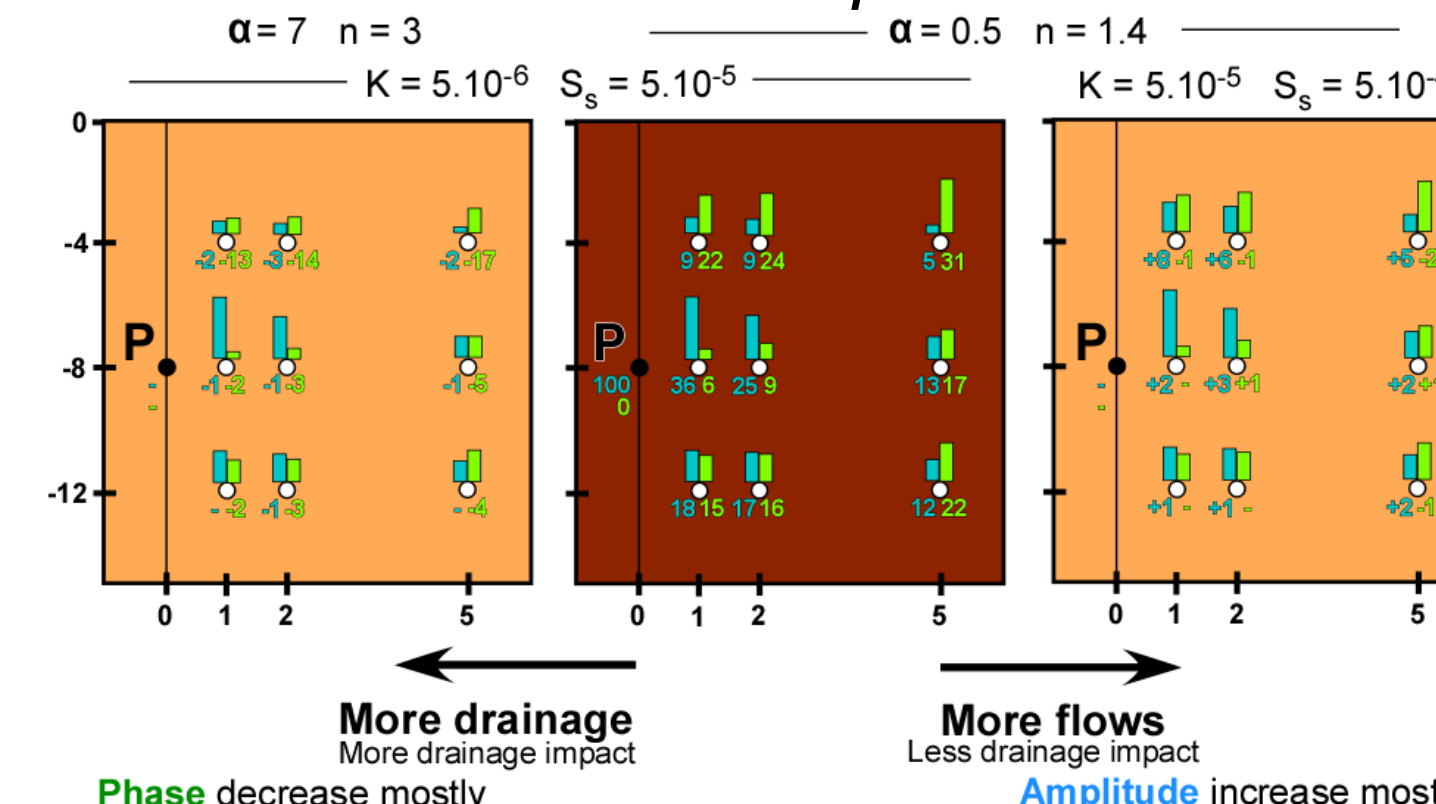
Conclusions :

- Impacts near the capillary fringe are more important on the relative responses than the absolute ones.
- Among the tested properties K is the only one to significantly influence the amplitude responses.
- S_S and n properties influence mostly the phase responses.
- α is less impacting than the other properties.

Absolute responses



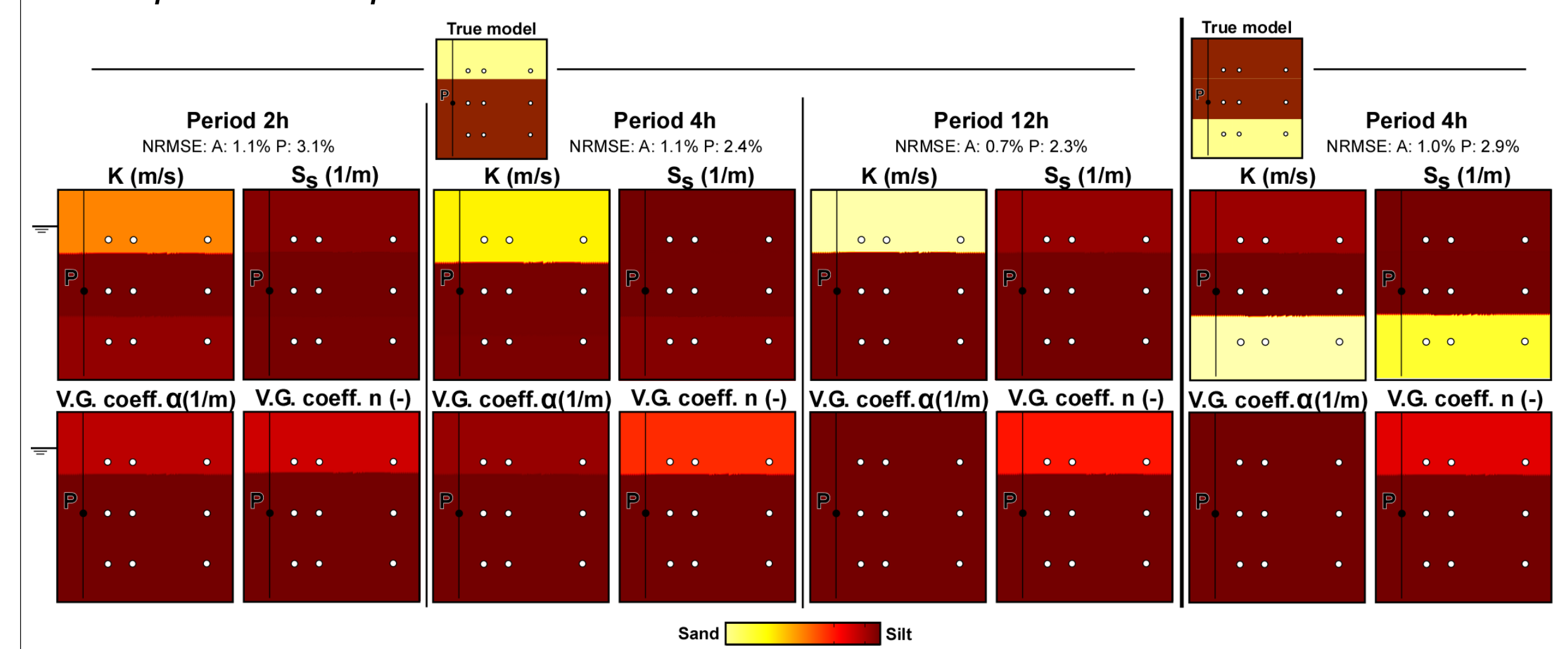
Relative responses



IMAGING POTENTIAL

We have collected, from our model, responses to periodic signals with different periods in simplified heterogeneous media (near-capillary fringe or deep heterogeneity). Hydraulic tomographies have then been performed, starting from homogeneous models, with these sets of collected responses (fig. 4). The inversion sequentially optimized K with the amplitude responses and then S_S , α and n with the phase responses.

▼ (fig.4) Silty soils tomography results for an heterogeneity (sand) near the capillary fringe with three different periods of oscillations and an heterogeneity deeper in the aquifer.



Conclusions :

- K heterogeneity can be well characterized with the amplitude responses (better characterized with higher periods ?).
- Near-capillary fringe heterogeneity is better characterized by α and n , while a deeper heterogeneity by S_S .
- Impact of the Van Genuchten coefficients on the responses may be period-dependent ? → Low period for α , high period for n ?

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