How clay layers control basin-scale fluid and heat flow

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1. Introduction

- The objectives are to explore the role clay layers play on restricting groundwater flow on basin and continental scales.
- The models are based on permeability and stratigraphy data compilations of North America and Europe.
- A model sensitivity study investigates the influence of key parameters including drainage density, hydraulic gradient, clay layer properties (i.e. thickness, depth, mineralogy, and anisotropy), and permeability of the non-clay layers.

2. Methods

- We modeled fluid flow and heat conduction and advection.
- Fluid flow, heat flow and all related parameters are modeled using SUTRA.

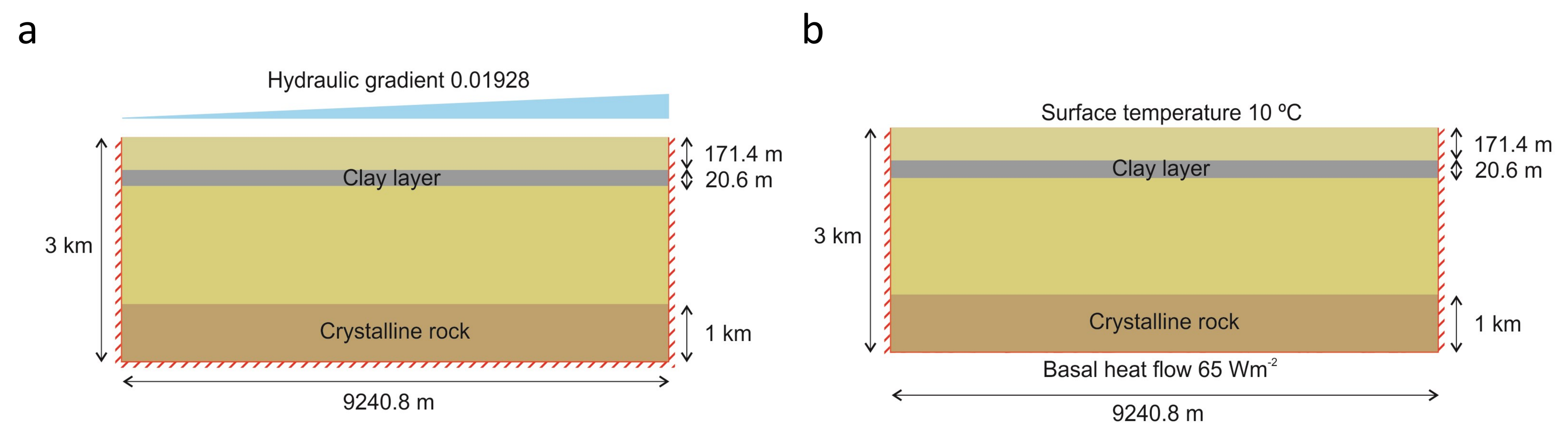

Fig. 1. Conceptual models for (a) fluid flow; and (b) heat flow with base case scenario values.

Table 1. Base case parameter values and their range of variations.

Parameter	Base case value	Variation range
River distance	9240.8 m	3.029 km – 200 km
Hydraulic gradient	0.018	0.0 – 0.68
Clay content of the non-clay layer	0.019	0.0 – 0.55
Clay layer thickness	20.6 m	4 – 299.3 m and 1e^{-5} – 100 m
Clay layer depth	171.4 m	5 – 1658 m
Clay layer anisotropy	100	1 – 1000

3. Results

- Base case scenario uses the median values of compiled data.
- Temperature change is compared to a case which ignores groundwater flow.
- Permeability and vertical velocity are plotted on logarithmic scales.
- Hydraulic head and fluid flux are shown.
- Black arrows represent directions of fluid velocity.

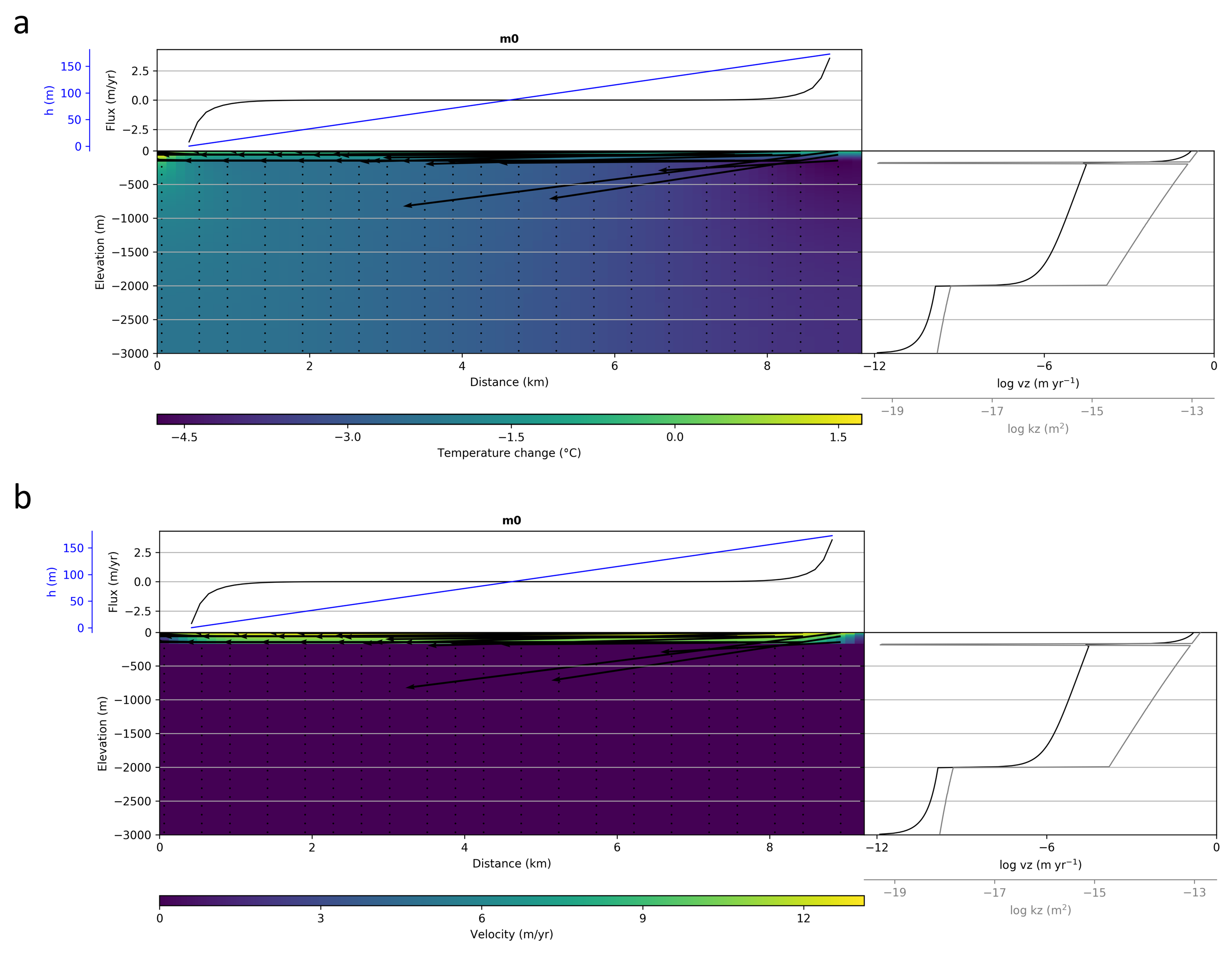

Fig. 2. Base scenario results. (a) temperature change (°C); and (b) vertical flow velocity (m/yr).

- The effect of clay layer's composition on the mean temperature change and vertical flow velocity in clay layer is displayed bellow which shows that thin clay layers can block groundwater flow.
- Mix clay layer consists of 50% Kaolinite and 50% Illite.

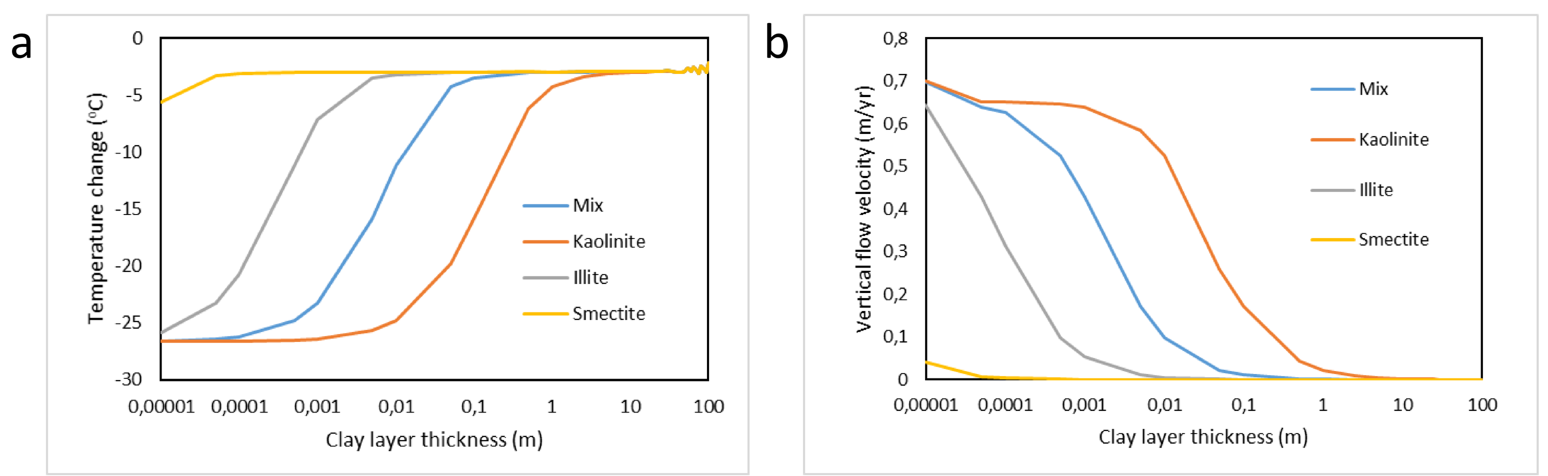

Fig. 3. (a) Temperature change (°C); and (b) vertical flow velocity (m/yr) for different types of clay layer as a function of clay layer thickness.

- The influence of different parameters on temperature change in the subsurface is shown bellow:

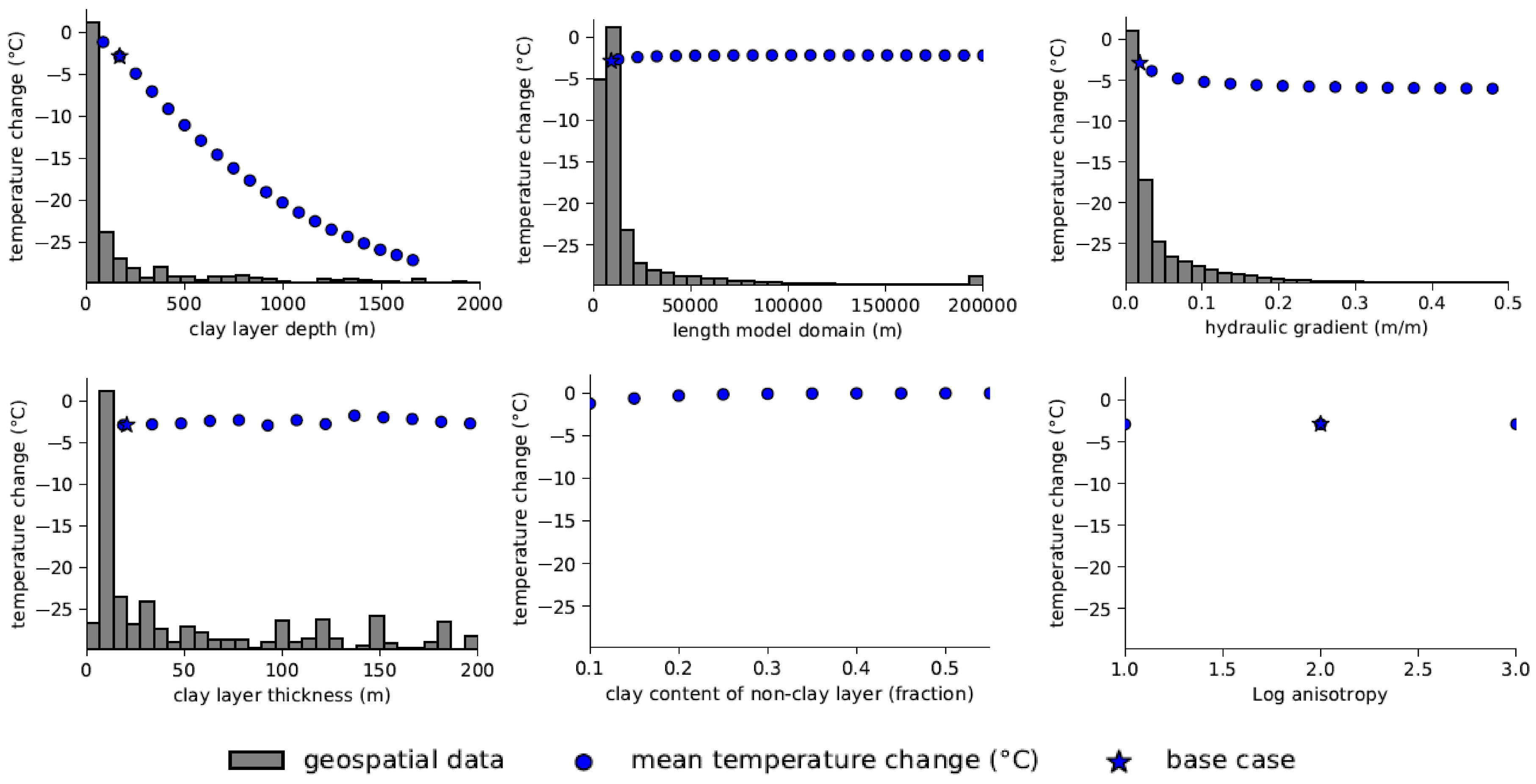

Fig. 4. Mean temperature change (°C) as a function of studied parameters.

- The effect of studied parameters on vertical fluid flow which results in different flow patterns in sedimentary basins is displayed bellow which shows that hydraulic gradient is the most influential parameter on vertical flow velocity.

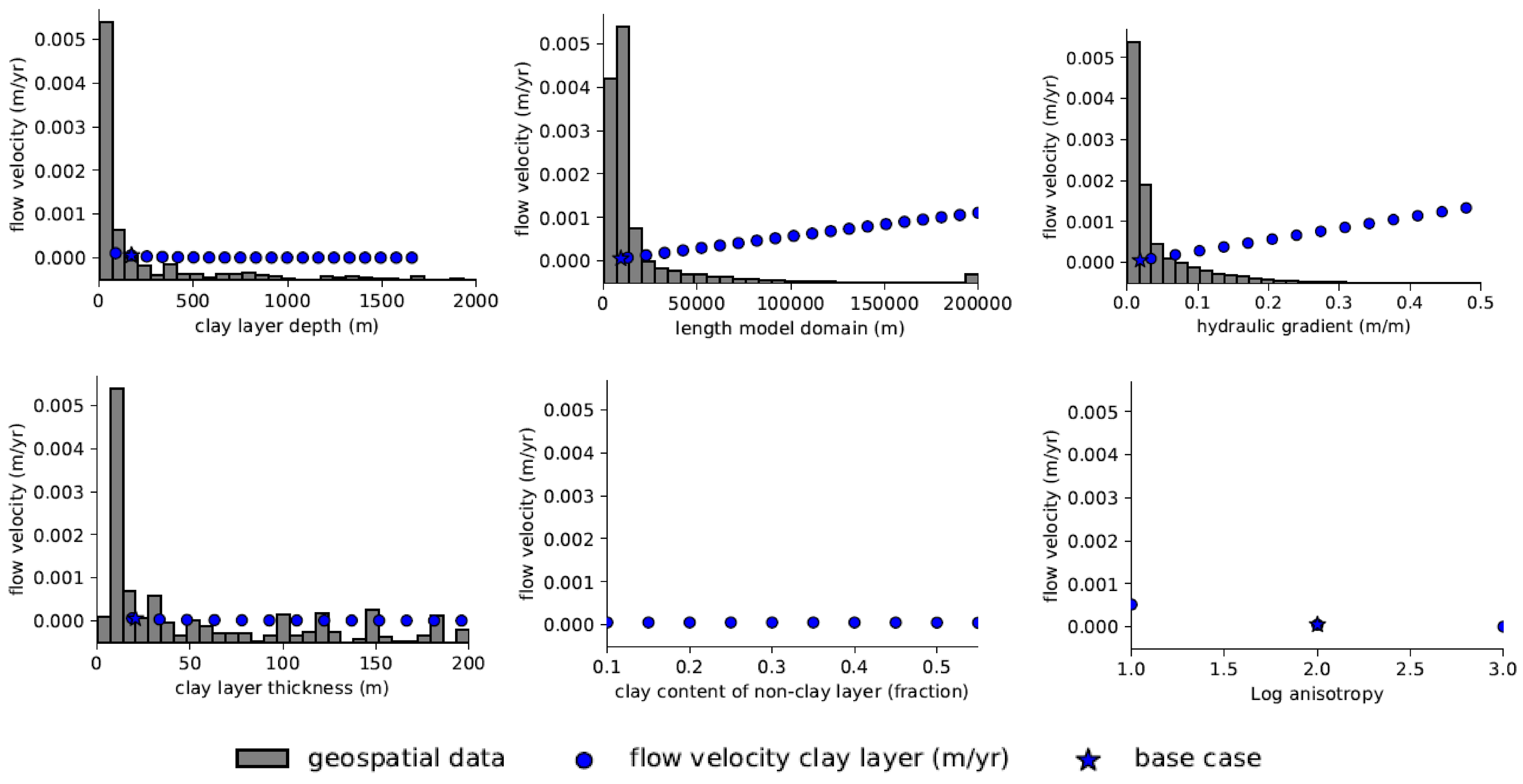

Fig. 5. Flow velocity in the clay layer (m/yr) as a function of studied parameters.

- The influence of each parameter on recharge is displayed bellow which shows that recharge is mostly influenced by hydraulic gradient.

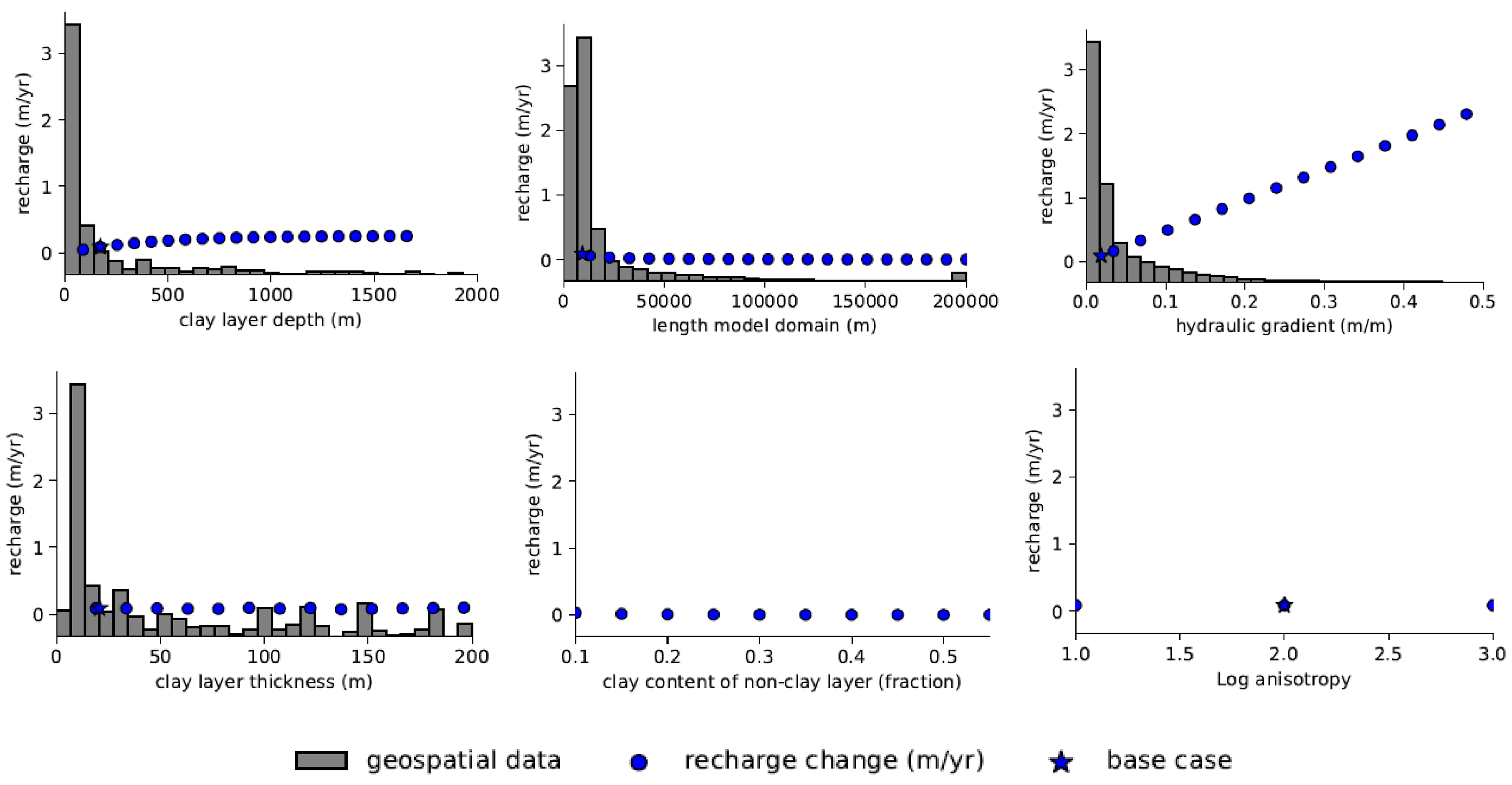

Fig. 6. Recharge (m/yr) as a function of studied parameters.

4. Conclusion

- The modeling results demonstrate only thin continuous clay layers are needed to block topography-driven flow ranging from 10 – 100 m, 1-10 cm and 0.1-1 mm for kaolinite, illite and smectite layers, respectively.
- A marine clay layer in North America basins with the median depth and thickness of (171.4 and 20.6 m) block most groundwater flow and reduces the cooling effect of groundwater flow to 2°C, whereas without clay groundwater cools the basin by 20°C.
- The flow velocity, recharge and temperature deviation due to the presence of a clay layer increases with increasing hydraulic gradient.
- For temperature change, the most sensitive parameter is clay layer depth and the model is insensitive to clay anisotropy and length of domain.
- The numerical results demonstrate that both basin and clay layer characteristics influence groundwater flow and heat transfer.