Temperature Distribution and Thermal Performance of an Aquifer Thermal Energy Storage System

Universiteit Utrecht

Sayantan Ganguly, Department of Earth Sciences, Utrecht University, The Netherlands

GEO

Subsurface Thermal Energy Storage

- Aquifers provide a large volume for storage of thermal energy with low cost of implementation and maintenance and with almost no adverse environmental effects.
- Storing the excess thermal energy in water by injecting it into an aquifer and extracting in time of demand is the main principle of an Aquifer Thermal Energy Storage (ATES) system.
- As a practical, environment friendly and economical system of storage of renewable thermal energy, the popularity of ATES systems is growing rapidly.
- Direct use of groundwater with relatively high volumetric heat capacity makes ATES systems more efficient than other heat storage systems.
- Using ATES systems for energy conservation reduces the dependence on fossil fuels and leads to energy savings, reduction of emission of greenhouse gases and significant reduction of cost for heating/cooling of buildings and districts.

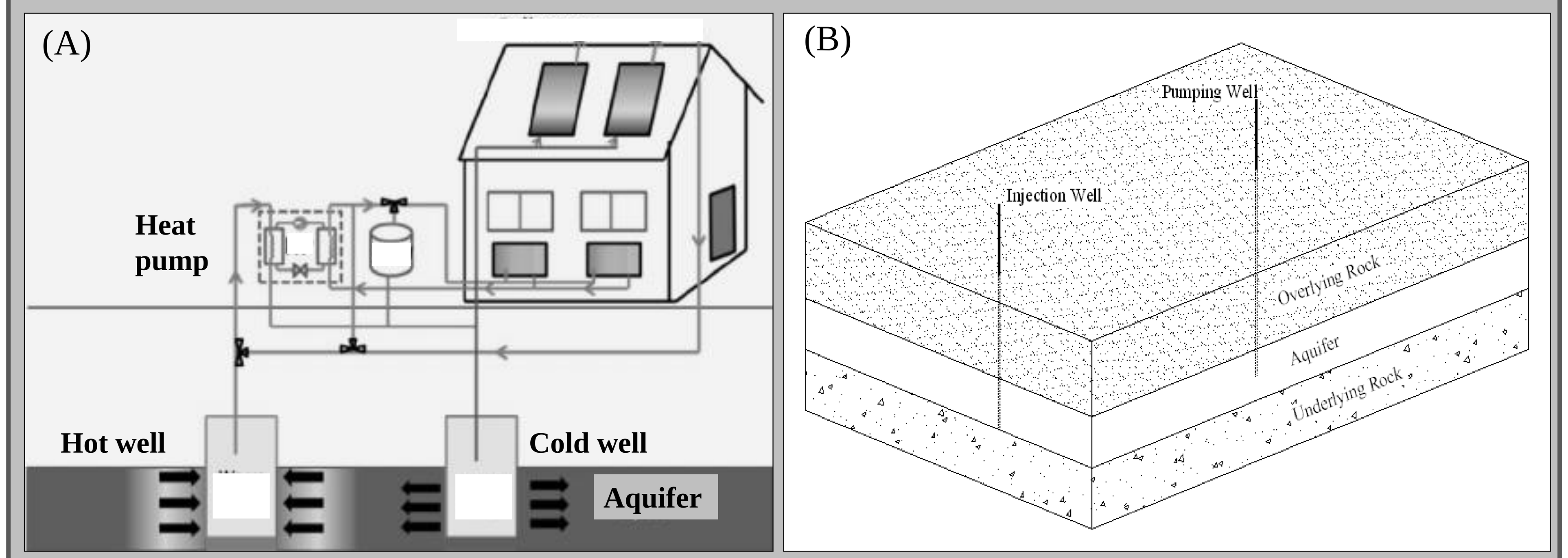

Fig. Schematics of an aquifer thermal energy storage system

Mathematical and Numerical Modeling

- The fluid flow and heat transport equations in porous media are solved in this study [1,2]

$$S\frac{\partial h}{\partial t} - \nabla\cdot\{K\cdot\nabla h\} = q_f$$

- 3D heat transport equation in porous media for single phase fluid flow

$$\frac{\partial}{\partial t}\{(1-\phi)\rho_r c_r T(x,y,z,t) + \phi\rho_w c_w T(x,y,z,t)\} + \nabla\cdot\{u_w\rho_w c_w T(x,y,z,t)\} + q_1 - q_2 = \nabla\cdot\{(\boldsymbol{\lambda}\cdot\nabla)T(x,y,z,t)\}$$

- The rock and water properties here are considered functions of temperature

$$\rho_w(T) = 1043.2 - 42.97\exp(0.007T)$$

$$c_w(T) = \{10.0002374\ 9816 + 8.0681764 \times 10^{-8}\mathrm{T} - 8.0367134 \times 10^{-10}\mathrm{T}^2\}^{-1}$$

$$\rho_r = \frac{2650}{1+(T-20)\times 0.5\times 10^{-4}}$$

$$c_r(T) = 1234.257 - 454.546\exp(-0.0039733482T)$$

- The numerical modeling of the ATES system is carried out using software code DuMux.
- The temperature of the injection water in summer is 35°C and in winter is 5°C.

Temperature distribution in the aquifer

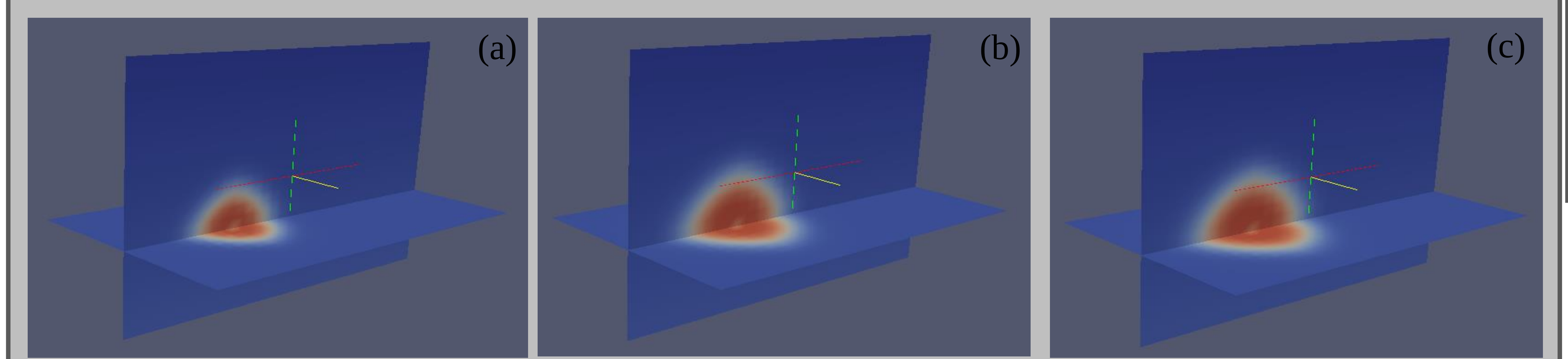

Fig. Temperature distribution in ATES system in summer at (a) 30 days, (b) 60 days and (c) 90 days

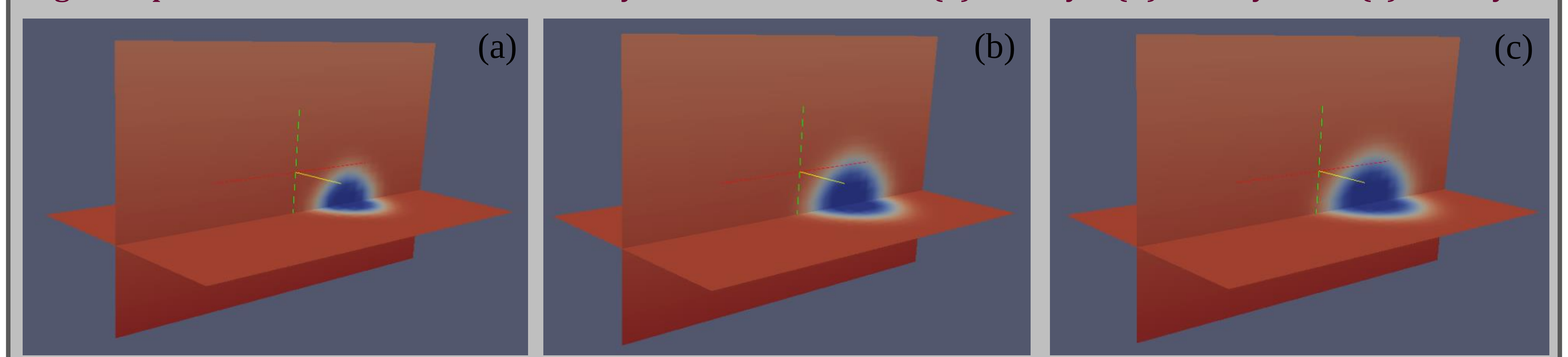

Fig. Temperature distribution in the ATES system in winter at (a) 30 days, (b) 60 days and (c) 90days

Parameter sensitivity

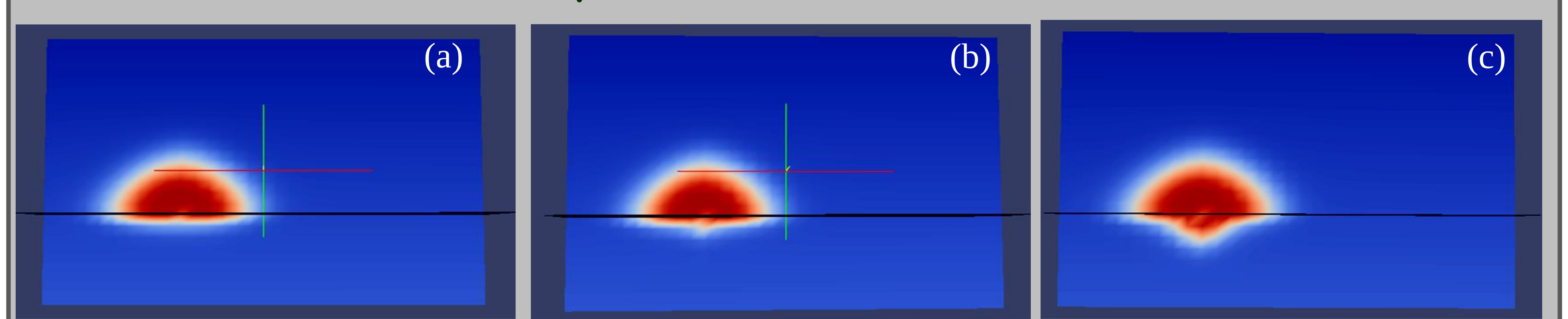

Fig. Temperature distributions in the ATES system after hot-water injection for 3 months for equal to a 10^{-20} m/s, b 10^{-17} m/s and c 10^{-15} m/s.

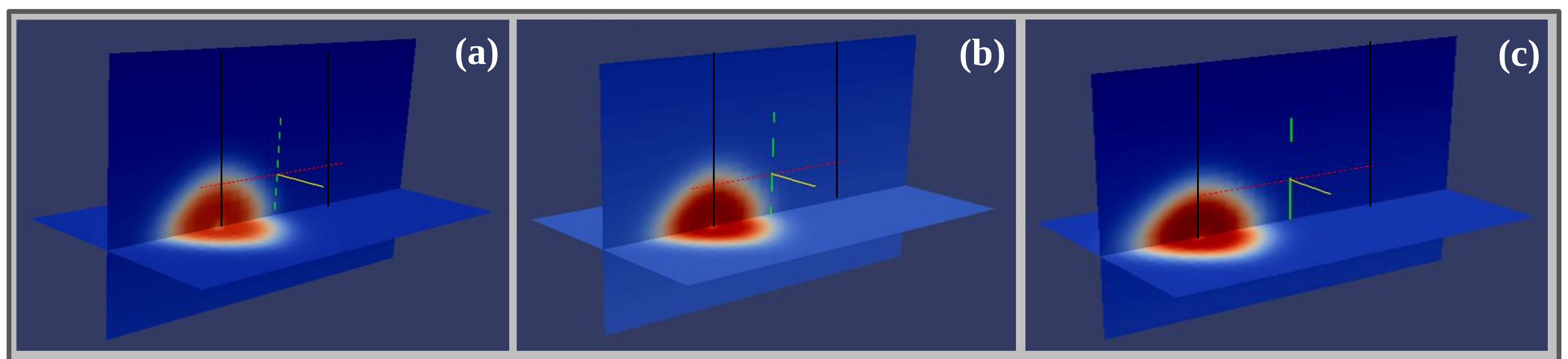

Fig. Temperature distributions in ATES system after hot-water injection for 3 months for *d*=equal to a 40 m, b 60 m and c 80 m.

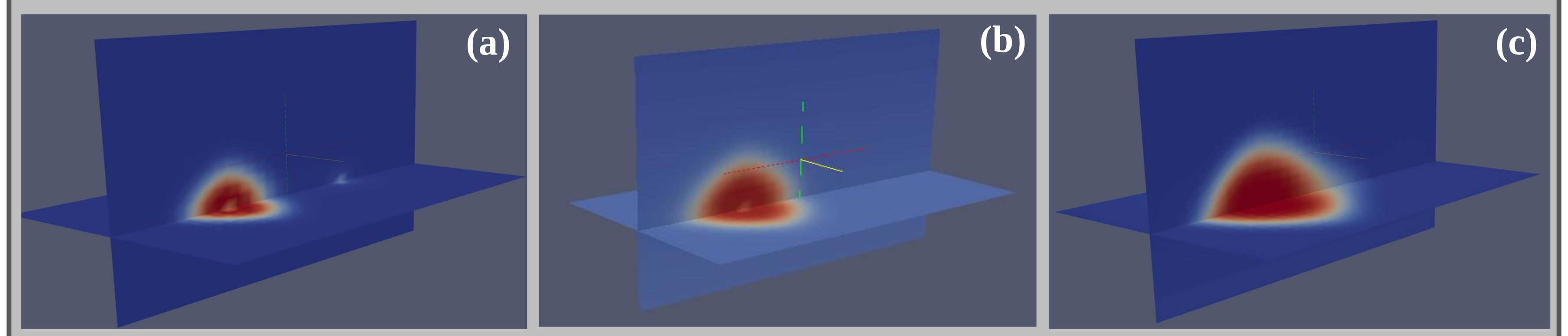

Fig. Temperature distributions in the ATES system after hot-water injection for 3 months for equal to a 18˚C, b 35˚C and c 70˚C.

Thermal-energy discharge

- The aim of the modeling and parameter studies presented in this paper is ultimately needed to maximize the energy production while ensuring safety from loss of efficiency by cooling of production wells.
- The thermal energy discharged by the ATES system

$$W = \eta Q \rho_w c_w \Delta T$$

$$\text{Heat recovery efficiency}(\eta)\ \frac{\int_0^{t_{prod}} \rho_w\cdot c_w\cdot Q_{prod}\cdot\left(T_{prod}-T_a\right)\cdot dt}{\int_0^{t_{inj}} \rho_w\cdot c_w\cdot Q_{inj}\cdot\left(T_{in}-T_a\right)\cdot dt}$$

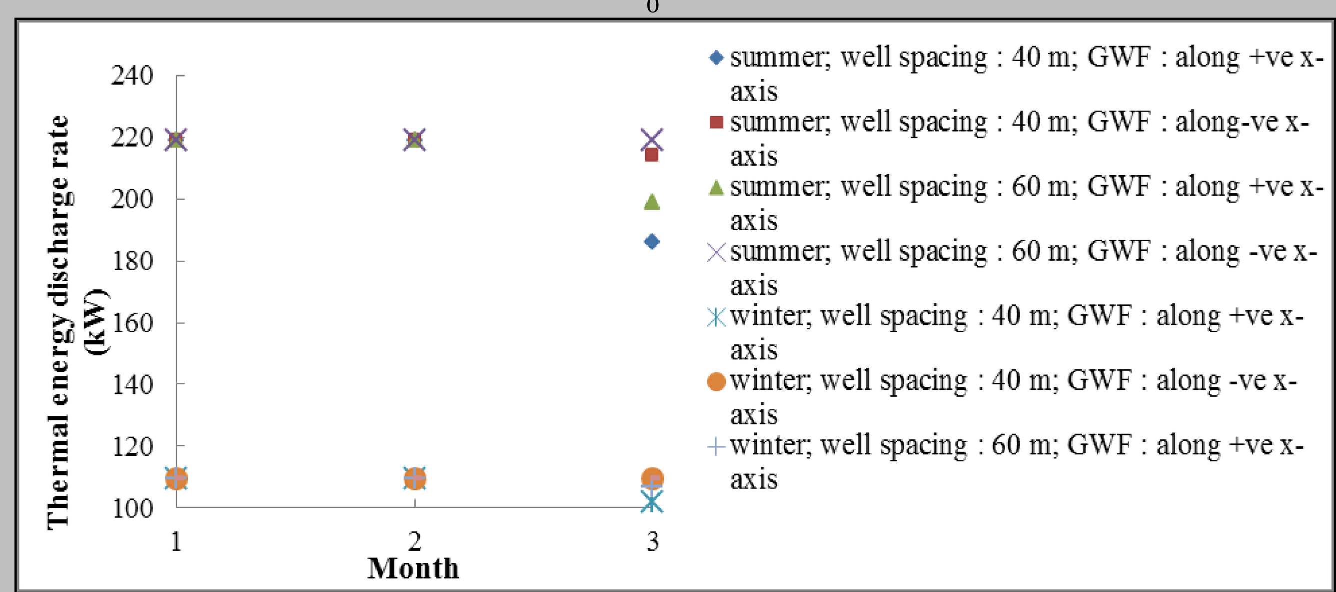

Fig. Variation of thermal energy discharge rate at the operation periods of 1, 2, and 3 months in summer and winter, for different and *RGF* directions.

- ATES system is capable of delivering 96.76 kW during winter for heating and 48.38 kW during summer for cooling, with *Q*=200 m³/day.
- When *Q* is increased to 300 m³/day, the energy discharge in winter becomes 145.14 kW and 72.57 kW in summer.
- An ATES system in a fertilizer factory in Anesong city, South Korea [2], for an area 500 m² requiring heating/cooling, the thermal energy demand is around 70 kW. Hence the present ATES system can cater this site both in summer and winter, when the *Q*> 300 m³/day.
- But when *Q*>300 m³/day at the end of the cycle (90 days) the thermal-breakthrough becomes imminent (α=0.97). Hence increasing the well spacing is necessary to ensure safety from thermal-interference resulting from breakthrough.

Simulation of field study

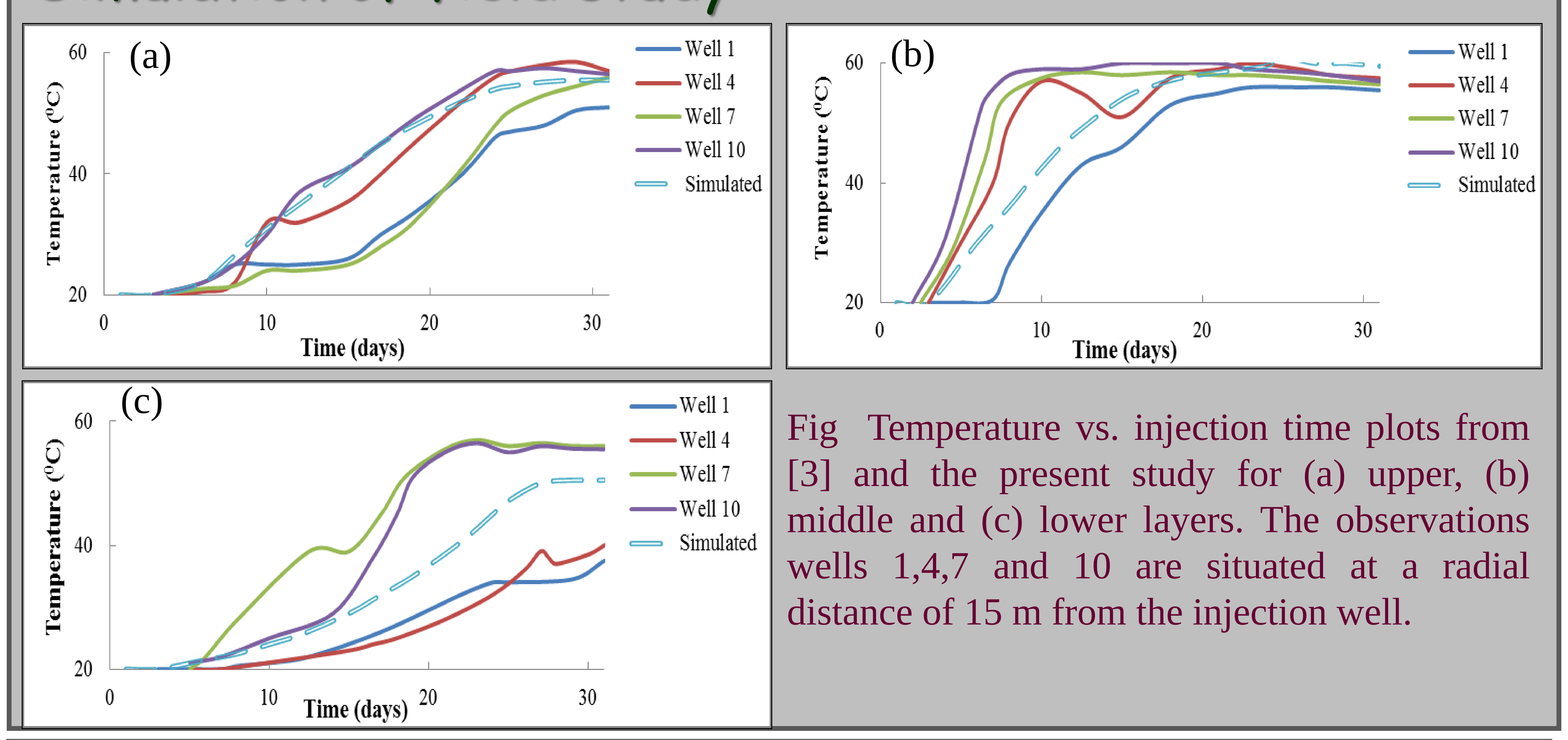

Fig Temperature vs. injection time plots from [3] and the present study for (a) upper, (b) middle and (c) lower layers. The observations wells 1,4,7 and 10 are situated at a radial distance of 15 m from the injection well.

References

[1] Ganguly S., M.S. Mohan Kumar, A. Date, A Akbarzadeh (2017) Numerical Investigation of Temperature Distribution and Thermal Performance while Charging-Discharging Thermal Energy in Aquifer. *App Ther Engg.* 115: 756-773.

[2] Ganguly S., M.S. Mohan Kumar (2014) Numerical modeling for transient temperature distribution in an aquifer thermal energy storage system. CMWR 2014 conference abstracts. Stuttgart, Germany

[3] Kim, J., Y. Lee, W.S. Yoon, J.S. Jeon, M.H. Koo., Y. Keehm. (2010) Numerical modeling of aquifer thermal storage system. Energy 35: 4955-4965.

[4]. Molz F.J, J.G. Melville, A.D. Parr, D.A. King, M.T. Hopf. (1983) Aquifer thermal energy storage: a well doublet experiment at increased temperatures. *Wat Resour Res* 19(1):149–160.

Email: s.ganguly@uu.nl/sayforall@gmail.com