Temperature distribution in coastal aquifers: Insights from groundwater modeling and field data

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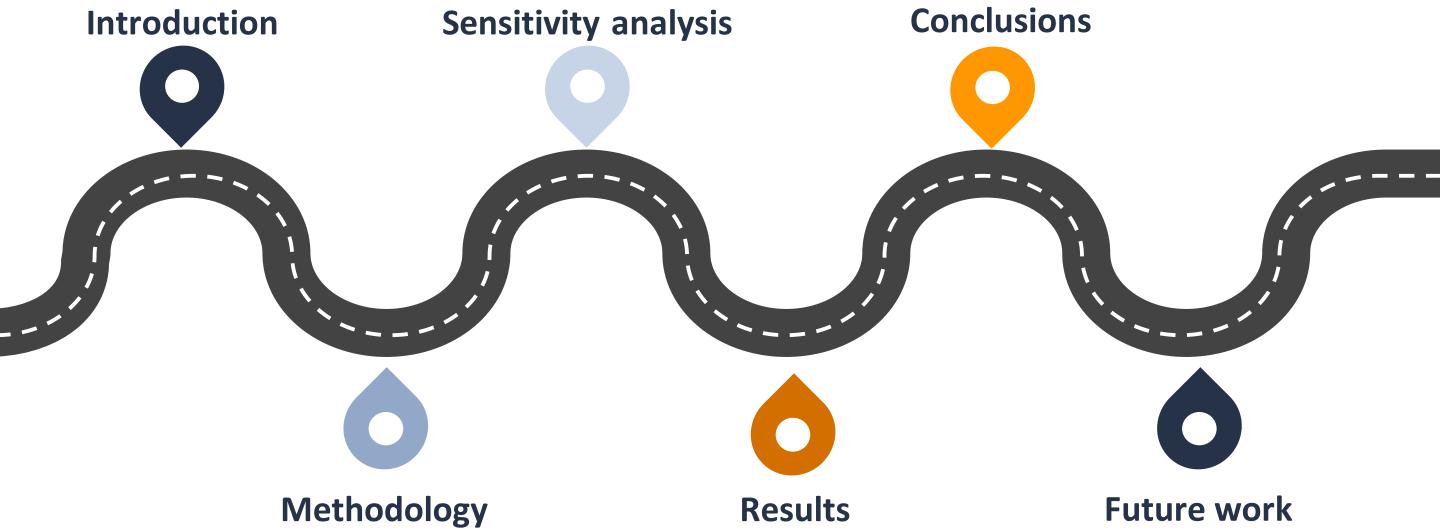


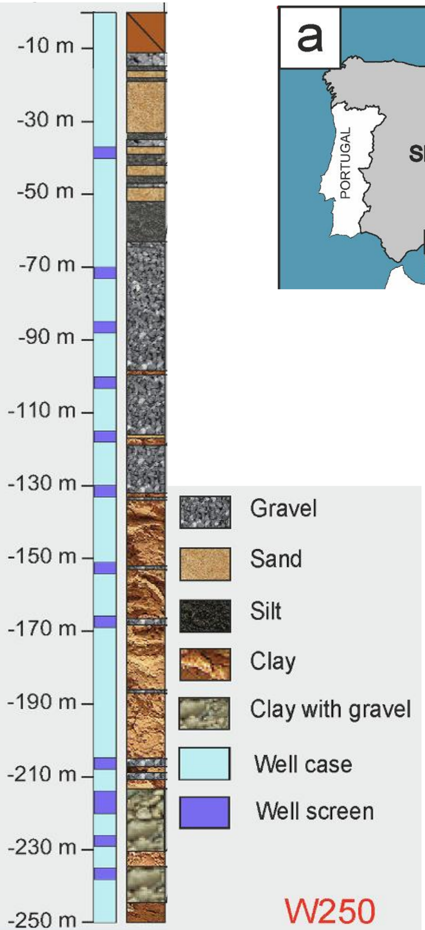
Introduction

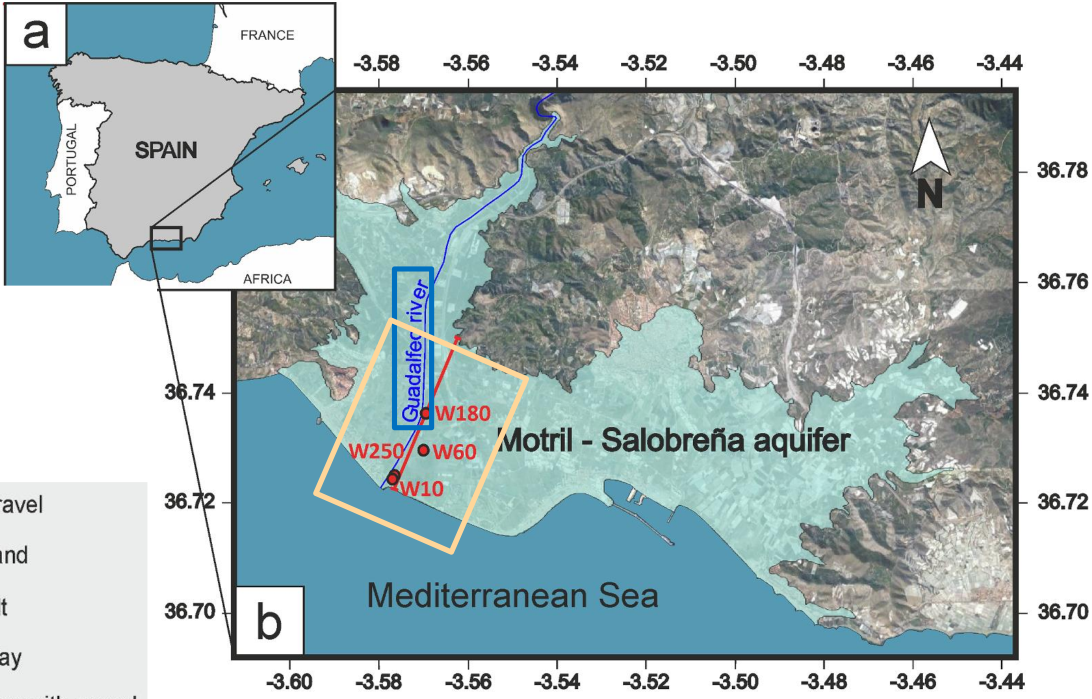
- Possible heat sources of coastal aquifer:

Surface water recharge → Geothermal heat → Sea infiltration

- This research considered all possible sources of heat in a coastal aquifer by using a combination of field data and numerical modeling
- This research considered the variable-density flow, coupled heat and solute transport to set up the model.
- The position of the freshwater-saltwater interface (FSI) and its effect on temperature distribution have been modeled

Research area

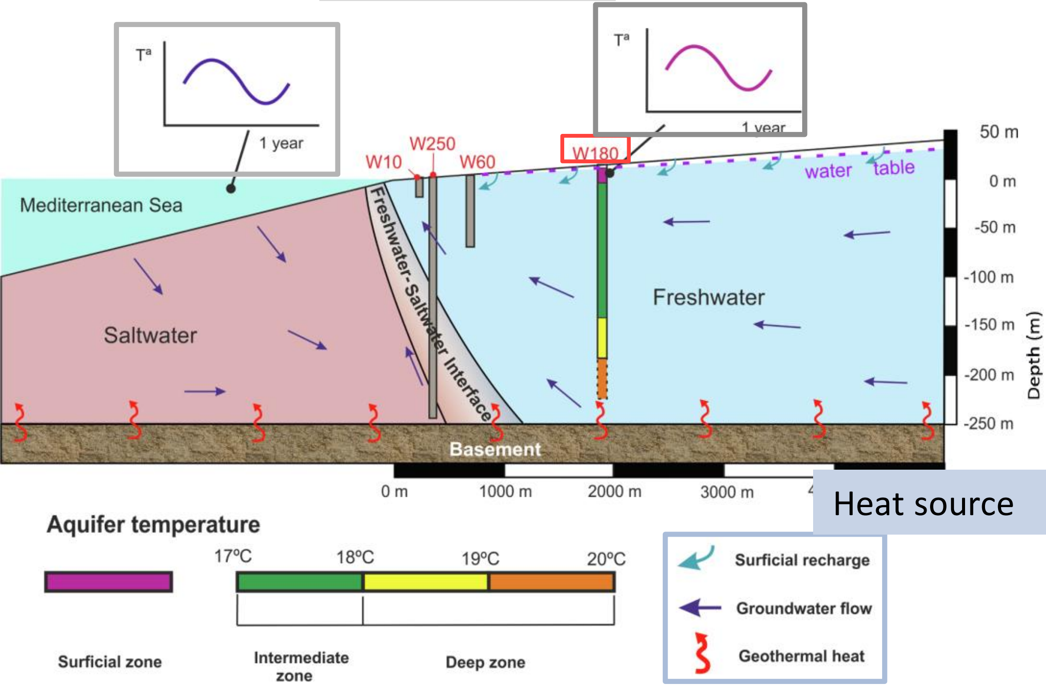




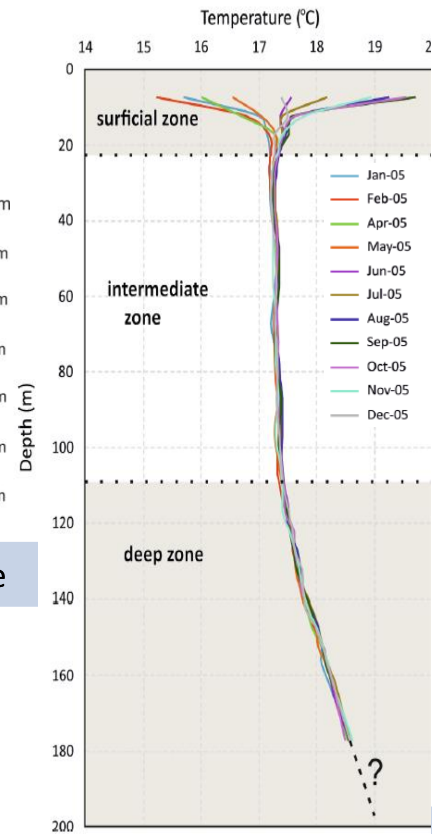
Introduction

Temperature vertical profiles in W180

Seasonal change



Heat source



Thermal conceptual model

Methodology

Heat transport is analogous to solute transport in groundwater modeling, adapted equation to assign suitable thermal parameters for temperature species

This research use SEAWAT to run the numerical model

Solute transport equation

$$\left(1+\frac{\rho_b K_d^k}{\theta}\right)\frac{\partial(\theta C^k)}{\partial t} = \nabla\left[\theta\left(D_m^k + \alpha\frac{q}{\theta}\right)\nabla C^k\right] - \nabla(qC^k) - q_s' C_s^k$$

Heat transport equation

$$\left(1+\frac{1-\theta}{\theta}\frac{\rho_s}{\rho}\frac{C_{Psolid}}{C_{Pfluid}}\right)\frac{\partial(\theta T)}{\partial t} = \nabla\left[\theta\left(\frac{k_{Tbulk}}{\theta\rho C_{Pfluid}} + \alpha\frac{q}{\theta}\right)\nabla T\right] - \nabla(qT) - q_s' T_s$$

$$K_d^t = \frac{C_{Psolid}}{C_{Pfluid*\rho}}$$

$$D_m^t = \frac{k_{Tbulk}}{\theta\rho C_{Pfluid}}$$

D_m^T : Thermal conduction

ρ_b : bulk density of solid

K_d^k : distribution coefficient of species k

C^k : concentration of species k

D_m^k : molecular diffusion coefficient

α : dispersivity tensor

q : specific discharge

q_s' : fluid source or sink

C_s^k : is the source or sink concentration of species k

ρ_s : density of the solid

ρ :fluid density

C_{Psolid}:specific heat capacity of the solid

C_{Pfluid}:specific heat capacity of the fluid

T:temperature

k_{Tbulk}:bulk thermal conductivity of the aquifer material

T_s:source temperature

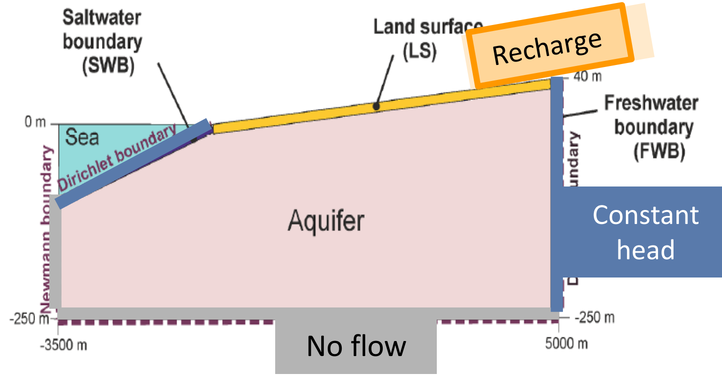
K_d^t= distribution coefficient of thermal

Bulk density : $\rho_b = \rho_s(1-\theta)$

Methodology

Table 1
Input values of the parameters for the s

Input parameters	Case study model
Specific storage	1E-5 m^{-1}
Specific yield	0.25
Porosity θ	0.3
Longitudinal dispersivity	10 m
Horizontal transverse dispersivity	5 m
Vertical transverse dispersivity	5 m
Freshwater salinity S_1	350 mg/L
Saltwater salinity S_2	35000 mg/L
Freshwater boundary head H_1	17 m
Saltwater boundary head H_2	0 m
Freshwater temperature T_1	16.7 °C
Saltwater temperature T_2	16.7 °C
Basement temperature T_3	20.05 °C
River water temperature oscillation TO_1	Sinus function 12–26 °C
Seawater temperature oscillation TO_2	Sinus function 14–24 °C
Molecular diffusion coefficient D_m^s	1E-10 m^2/d
Thermal conductivity of water k_{Tfluid}	0.58 W/m°K
Thermal conductivity of sediments k_{Tsolid}	2.9 W/m°K
Specific heat of water C_{Pfluid}	4186 J/kg°K
Specific heat of sediments C_{Psolid}	830 J/kg°K
Thermal diffusivity D_m^T	0.15 m^2/d
Bulk thermal conductivity k_{Tbulk}	1.8 W/m°K
Thermal distribution factor K_d^t	2E-7 L/mg
Density change with concentration	0.7
Density change with temperature	−0.375 kg/(m^3 °C)
Density vs pressure head slope	0.00446 kg/m^4
Bulk density ρ_b	1800 kg/m^3
Reference temperature	25 °C
Viscosity vs concentration slope	1.923E-6 m^4/d
Reference viscosity	86.4 kg/ m d



Constant head and salinity

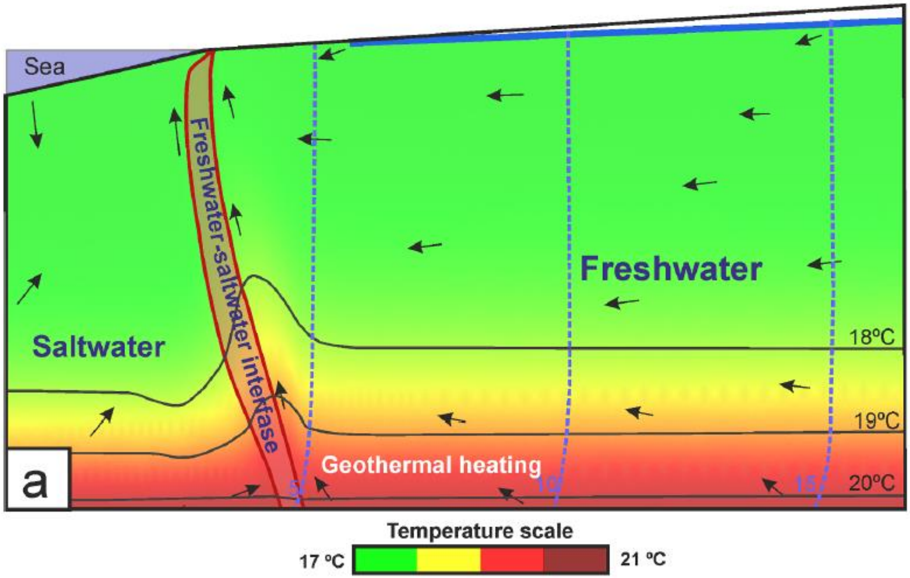
Constant thermal boundary

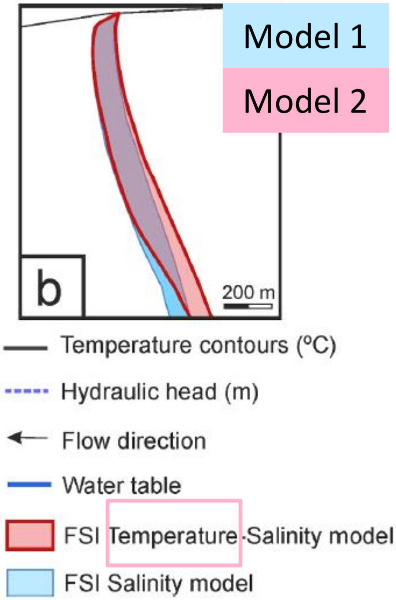
Seasonal temperature change

Methodology

Compare FSI position between Model 2 and Model 1

Freshwater-saltwater interface (FSI)



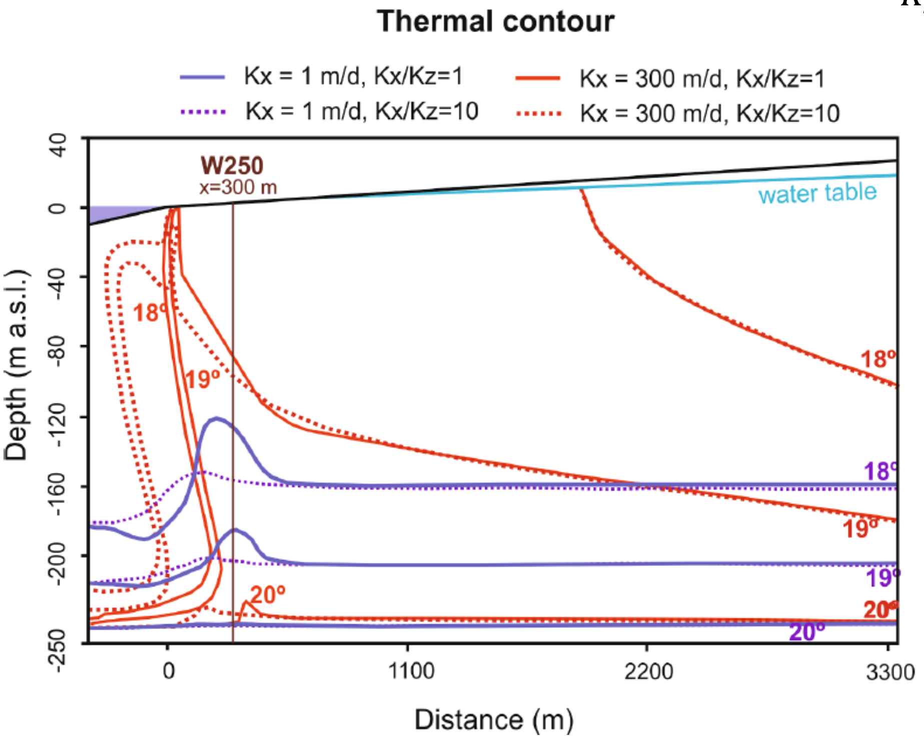


Model 2 thermal distribution

Sensitivity analysis

Sensitivity analysis of hydraulic conductivity

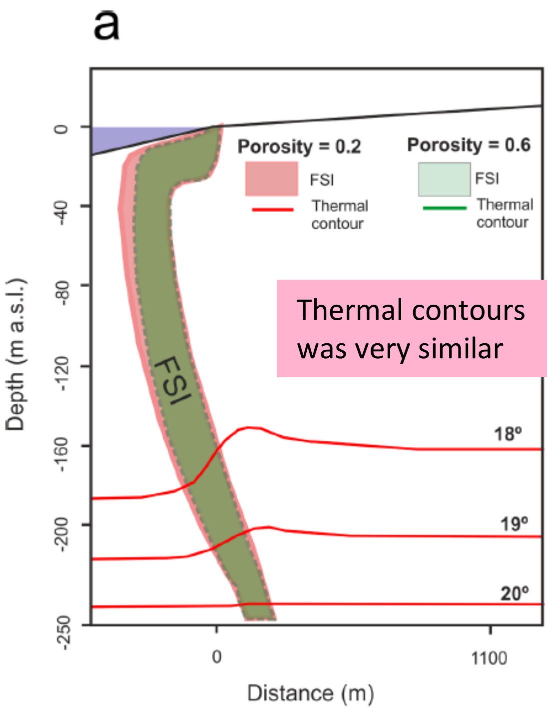
K_x/K_z :Anisotropic ratios



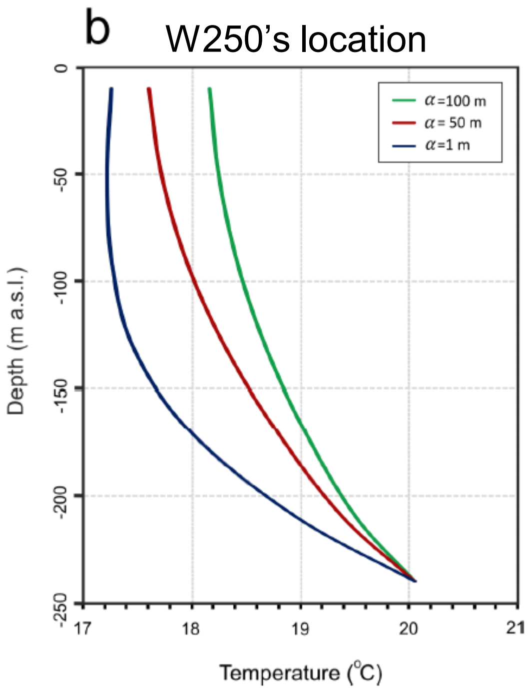
Sensitivity analysis

Sensitivity analysis of *Porosity* θ

Sensitivity analysis of Dispersivity α



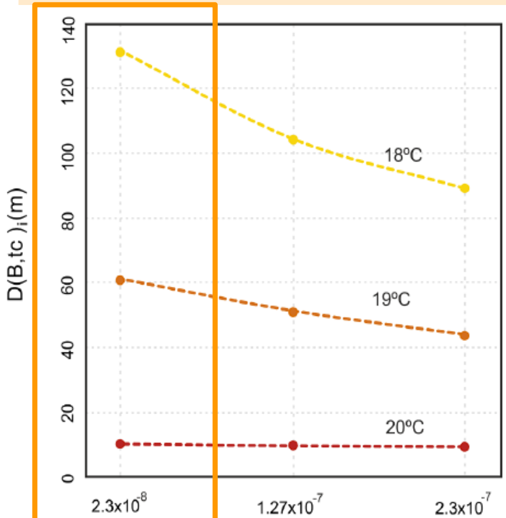
Thermal contours was very similar



Sensitivity analysis

$$K_d^t = \frac{C_{Psolid}}{\rho C_{Pfluid}}$$

Thermal distribution coefficient K_d^t



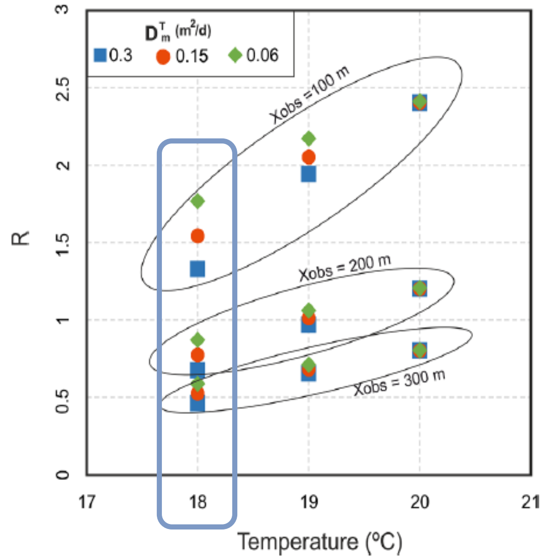
minimum

mean

maximum

$$D_m^T = \frac{k_{Tbulk}}{\theta \rho C_{Pfluid}}$$

Thermal diffusivity D_m^T



$$R = \frac{Z_{sl} - Z_{tci}}{X_{obs}}$$

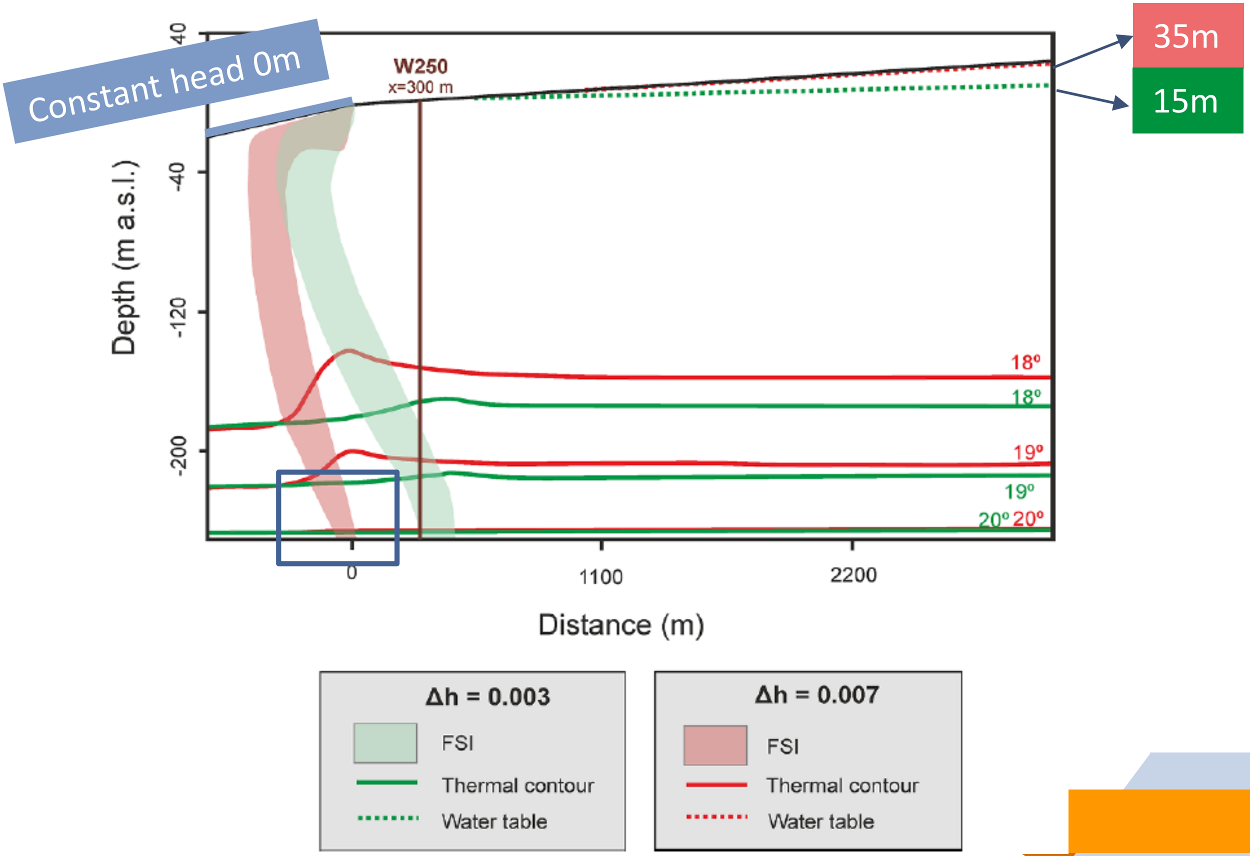
D(B,tc): vertical distance from the aquifer basement to each thermal contour

Z_{sl}= the elevation of sea level

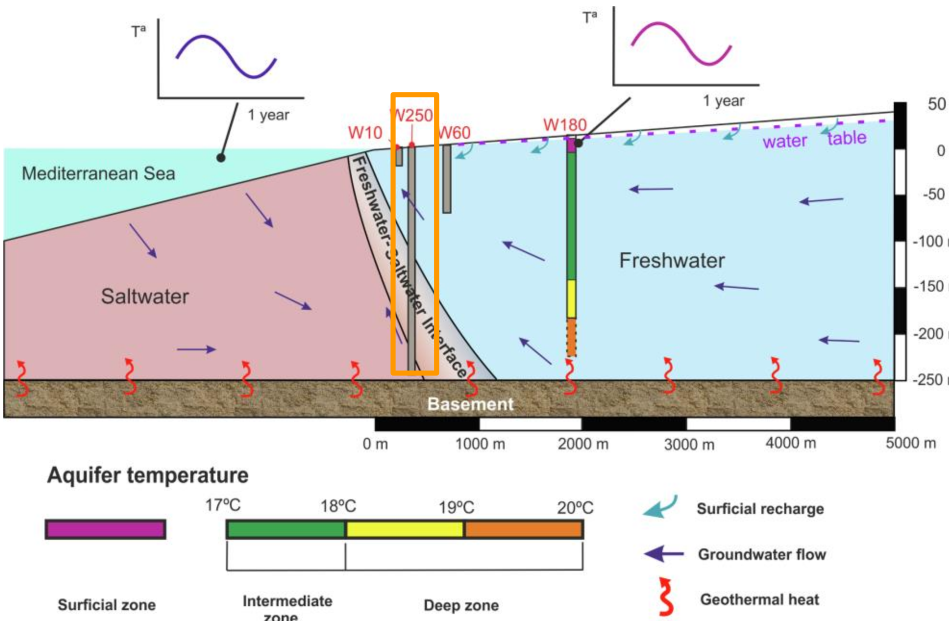
Z_{tci}= the elevation of the thermal contour

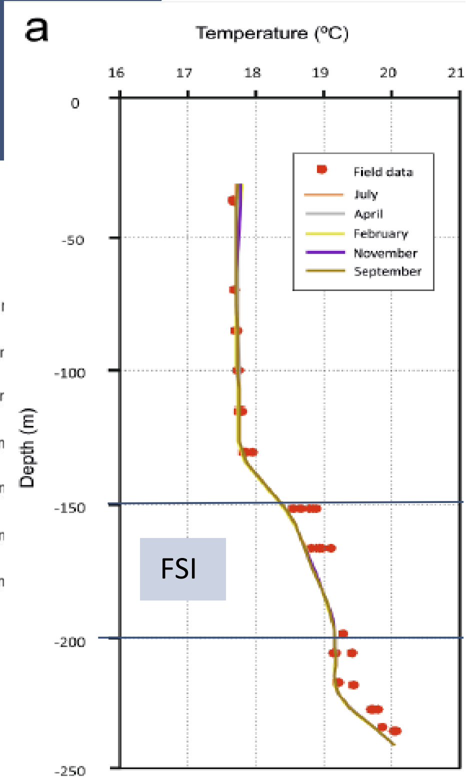
Sensitivity analysis

Sensitivity analysis of hydraulic gradient Δh



Results

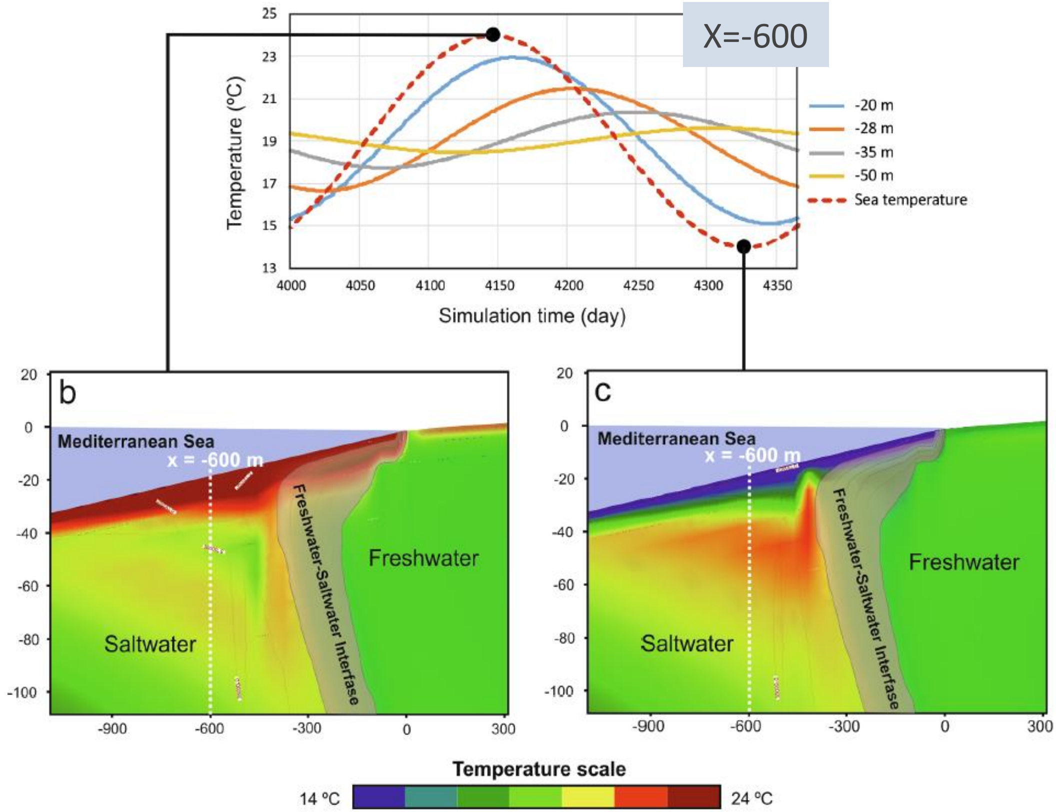




W250 V.S. Model x=300m

to set up, the basement has fixed temperature 20.05

Compare the temperature distribution



Conclusions

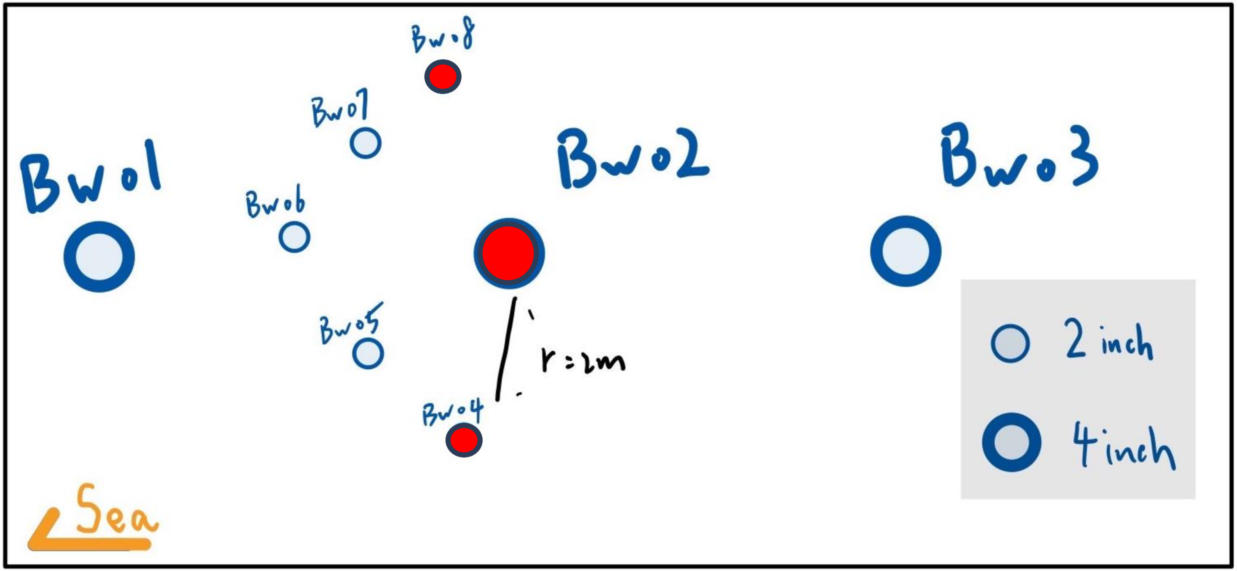
- K is the most controlling parameter in the temperature distribution of a coastal aquifer
- The Kx/Kz ratio had a notable influence on the vertical component of heat transport
- This research is the first in considering all possible sources of heat in a coastal aquifer simultaneously by using a combination of field data and numerical modeling.
- FSI is the thermal barrier that separates the temperature of the saltwater and freshwater
- In this study, we discussed the major processes and the effect of parameters on the application of temperature in coastal aquifers.

Future work

- Because of the deterioration of marine environment, it is necessary to identify the groundwater flow's direction

ow's

eld in



Change heating well: BW08

Currently heating well: BW02

Thank you for listening

Result

模型hydraulic conductivity是照W250岩心

溫度邊界依據W180底部有20.05度固定溫度

右邊淡水16.7度(中間那段溫度approximate value)

水流邊界5000 mm/yr補注量，水流溫度計節變化

模型運行15年在第9年FSI跟地熱處於穩態，表層會季節性變化

Table 1
Input values of the parameters for the sensitivity analysis and study model.

Input parameters	Sensitivity analysis	Case study model	Source
Specific storage	1E-5 m^{-1}	1E-5 m^{-1}	Calvache et al. (2015)
Specific yield	0.25	0.25	Similar value to Calvache et al. (2009)
Porosity θ	0.2–0.6	0.3	Duque et al. (2008)
Longitudinal dispersivity	1–100 m	10 m	Sauffer et al. (2013)
Horizontal transverse dispersivity	0.5–50 m	5 m	Sauffer et al. (2013)
Vertical transverse dispersivity	0.5–50 m	5 m	Sauffer et al. (2013)
Freshwater salinityS_1	350 mg/L	350 mg/L	Field observations
Saltwater salinity S_2	35000 mg/L	35000 mg/L	Field observations
Freshwater boundary head H_1	15–35 m	17 m	Field observations
Saltwater boundary headH_2	0 m	0 m	Field observations
Freshwater temperature T_1	17.2 °C	16.7 °C	Field observations
Saltwater temperature T_2	13 °C	16.7 °C	Manca et al. (2004)
Basement temperature T_3	19–30 °C	20.05 °C	Field observations
River water temperature oscillation TO_1	–	Sinus function 12–26 °C	Based on Duque et al. (2010)
Seawater temperature oscillation TO_2	–	Sinus function 14–24 °C	State of Harbors (Spanish Ministry)
Molecular diffusion coefficient D_m^s	1E-10 m^2/d	1E-10 m^2/d	Langevin et al. (2007)
Thermal conductivity of waterk_{Tfluid}	0.58 W/m°K	0.58 W/m°K	Langevin et al. (2007)
Thermal conductivity of sediments k_{Tsolid}	1–6 W/m°K	2.9 W/m°K	Approximate value for gravel (Xiaoqing et al., 2018)
Specific heat of water C_{Pfluid}	4186 J/kg°K	4186 J/kg°K	Langevin et al. (2007)
Specific heat of sediments C_{Psolid}	100–1000 J/kg°K	830 J/kg°K	Approximate value for gravel (Xiaoqing et al., 2018)
Thermal diffusivity D_m^T	0.06–0.3 m^2/d	0.15 m^2/d	Calculated using eq. (4)
Bulk thermal conductivity k_{Tbulk}	0.87–4.37 W/m°K	1.8 W/m°K	Calculated using eq. (5)
Thermal distribution factor K_d^t	2E-8 – 2E-7 L/mg	2E-7 L/mg	Calculated using eq. (3)
Density change with concentration	0.7	0.7	Langevin et al. (2007)
Density change with temperature	−0.375 kg/(m^3 °C)	−0.375 kg/(m^3 °C)	Langevin et al. (2007)
Density vs pressure head slope	0.00446 kg/m^4	0.00446 kg/m^4	Langevin et al. (2007)
Bulk density ρ_b	1800 kg/m^3	1800 kg/m^3	Calculated with $\rho_b = \rho_s(1-\theta)$
Reference temperature	25 °C	25 °C	Langevin et al. (2007)
Viscosity vs concentration slope	1.923E-6 m^4/d	1.923E-6 m^4/d	Langevin et al. (2007)
Reference viscosity	86.4 kg/ m d	86.4 kg/ m d	Langevin et al. (2007)

Table 2

Hydraulic conductivity values defined in each layer of the study model.

	Thickness (m)	Hydraulic conductivity (m/d)
Layer 1	16	Kx = Ky = 5 and Kz = 0.5
Layer 2	121	Kx = Ky = 400 and Kz = 40
Layer 3	63	Kx = Ky = 30 and Kz = 5
Layer 4	12	Kx = Ky = 150 and Kz = 1
Layer 5	35	Kx = Ky = 20 and Kz = 2