Groundwater Quality 2019

IMPACT OF CLIMATE CHANGE AND LAND USE CHANGE ON GROUNDWATER QUALITY THROUGH CHANGES IN SUBSURFACE TEMPERATURES

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Groundwater quality and temperature

Summarizing possible temperature effects:

1. Low groundwater temperature is an intrinsic quality
2. Gas pressure effects / dissolved CO_2 and O_2 and redox conditions
3. Temperature affects geochemical equilibria: Van ‘t Hoff equation (esp. adsorption reactions)
4. Temperature affects chemical and microbial reaction rates: Arrhenius equation
5. Temperature effects on microbiology
6. Effects on contaminants’ mobility

Groundwater quality and temperature

Groundwater quality effects by underground thermal energy storage (UTES) or aquifer thermal energy storage (ATES) have been studied by various researchers (e.g. Bonte, 2013; Hartog, 2013; Posemiers, 2014). Temperatures up to 25 ^oC. Main conclusions are that mixing effects of ATES systems are the most significant. As may be mobilized at moderate temperature increase (e.g. Bonte, 2013).

Saito et al. (2016) used a borehole heat exchanger to warm up an aquifer up to 7K. Riedel (2019) has presented a large set of groundwater quality data with associated naturally occurring temperature range between 5 and 20 °C. Both studies suggest that the temperature changes in these range affect the quality of the groundwater.

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Groundwater quality and temperature

Saito et al., 2016:

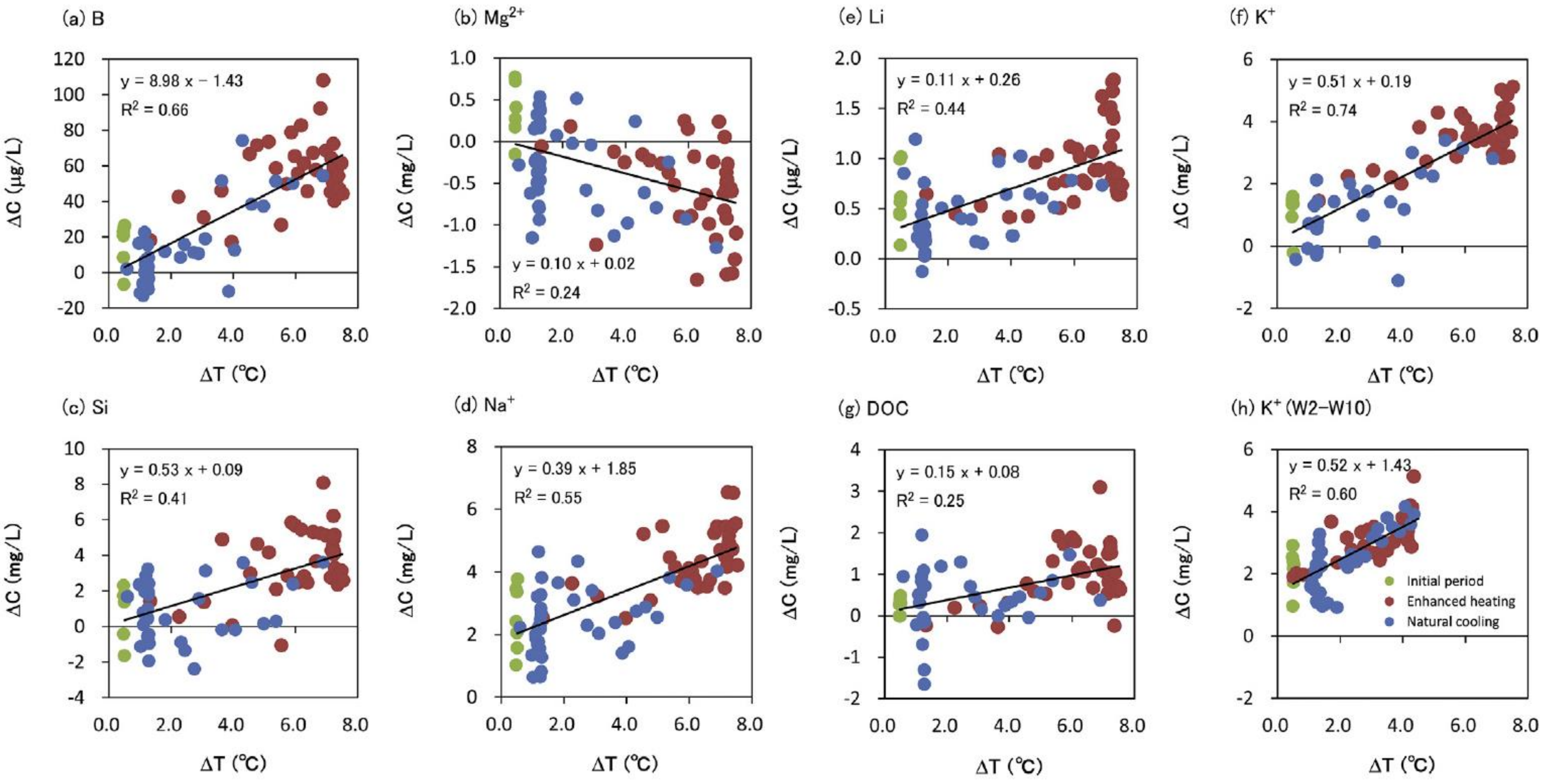

Fig. 6. Dual-Well Analysis (DWA) to determine the difference between subsurface temperatures in wells W10 (non-affected) and W1 (Note: between W10 and W2 in (h)) (ΔT) and the analogues difference in chemical concentration (ΔC) of (a) B, (b) Mg^{2+}, (c) Si, (d) Na^{+}, (e) Li, (f) K^{+}, (g) DOC, and (h) K^{+} (comparing Wells 2 and 10) in the groundwater of the upper, marine aquifer.

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Groundwater quality and temperature

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Riedel, 2019:

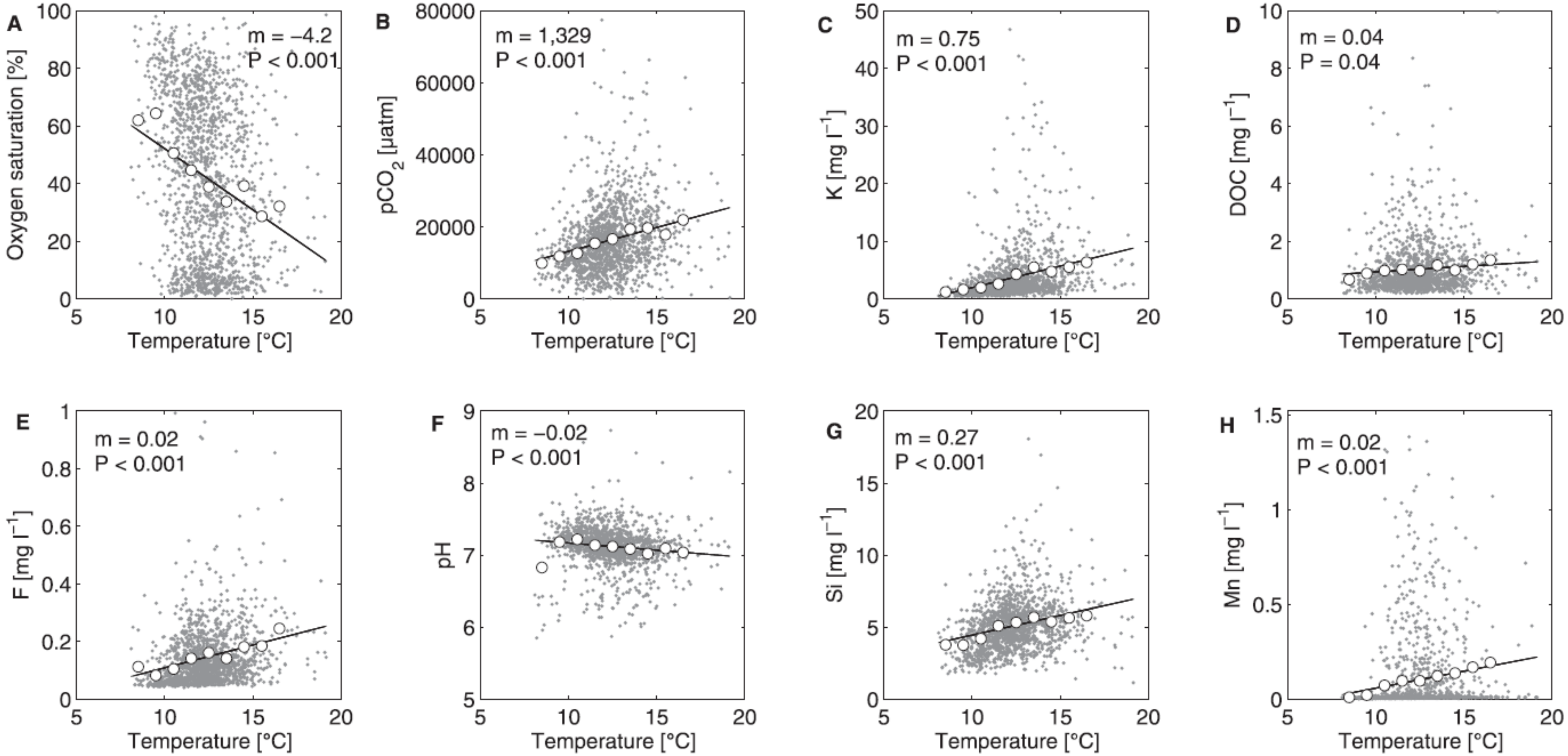

Fig. 2. Temperature differences are associated with differences in groundwater quality. Relation between *in-situ* groundwater temperature and saturation of dissolved oxygen (A), pCO_2 (B), potassium (C), dissolved organic carbon (D), fluoride (E), pH (F), Si (G) and Manganese (H) in groundwater sampled in n = 1486 wells. m denotes the trend for a given parameter associated with a temperature change of +1 K calculated using an ordinary least regression analysis. *P* indicates the statistical level of significance for the regression analysis. In addition, parameter values were binned at increments of 1 K. The averages calculated for each bin are indicated by the white circles.

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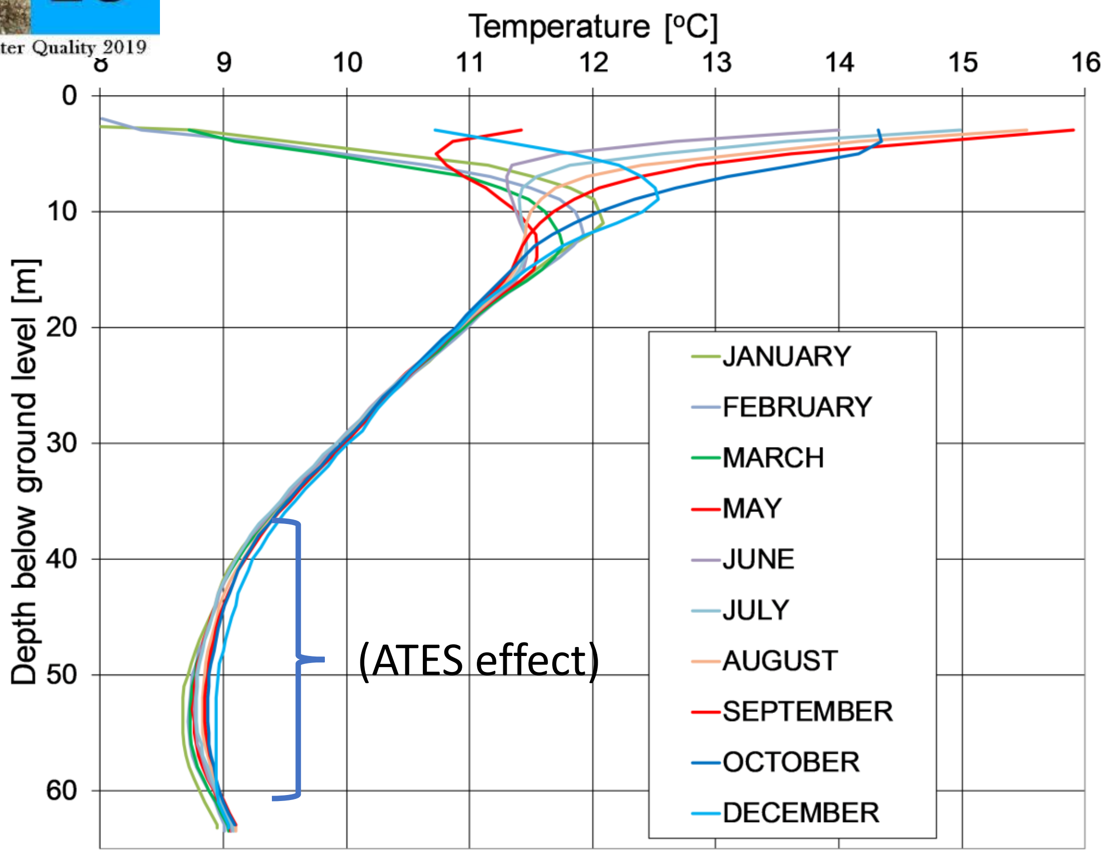
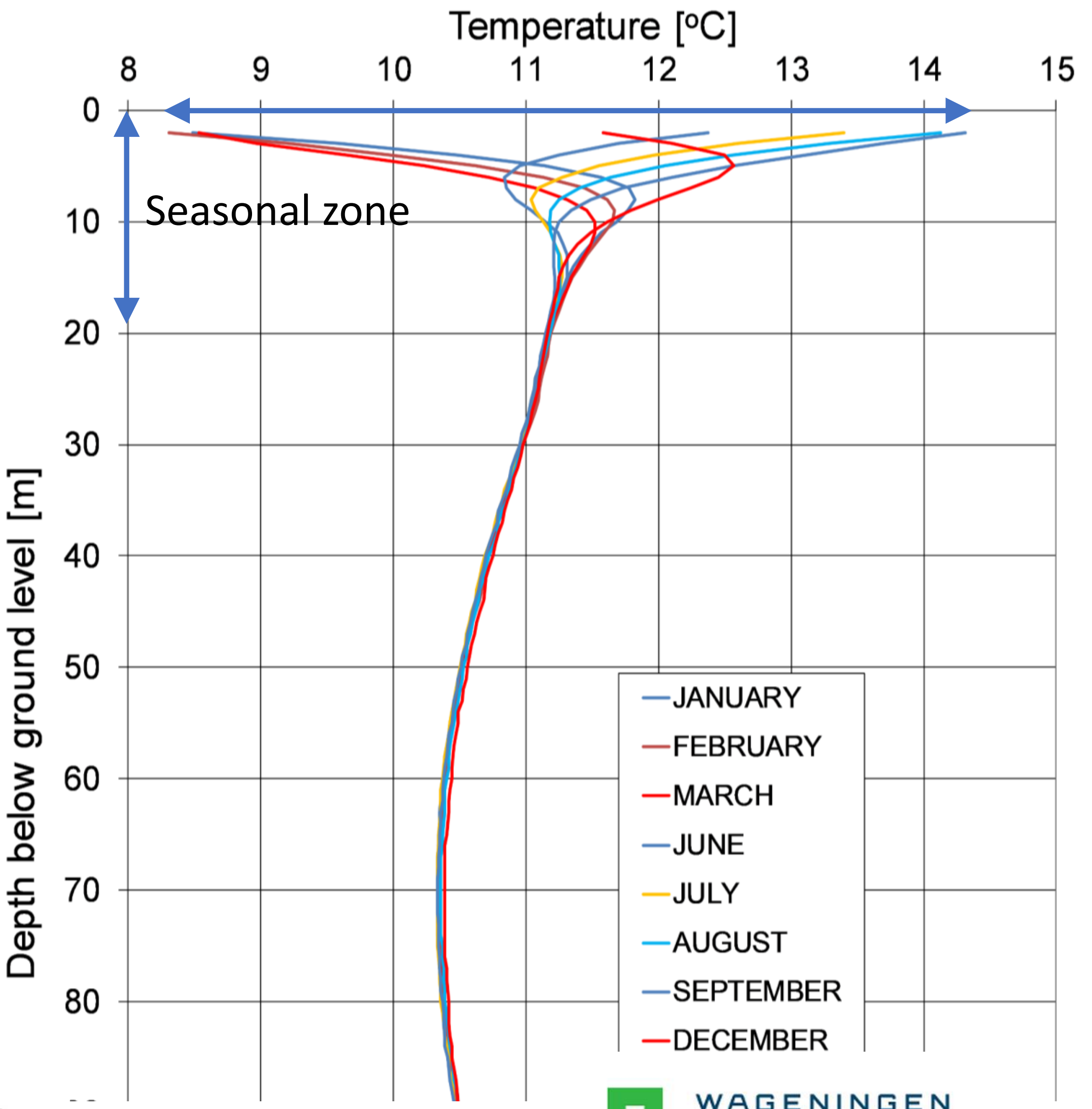
Subsurface and groundwater temperature

Near the surface, the temperatures are influenced by diurnal and seasonal fluctuations of the ground surface temperature (GST).

These fluctuations are attenuated in time and with depth. The diurnal variation do not penetrate below depths of approx. 1.5 m, but the seasonal changes in temperature can be observed to depths of generally 10-20 m, depending on the thermal properties of the subsurface and vertical groundwater flow.

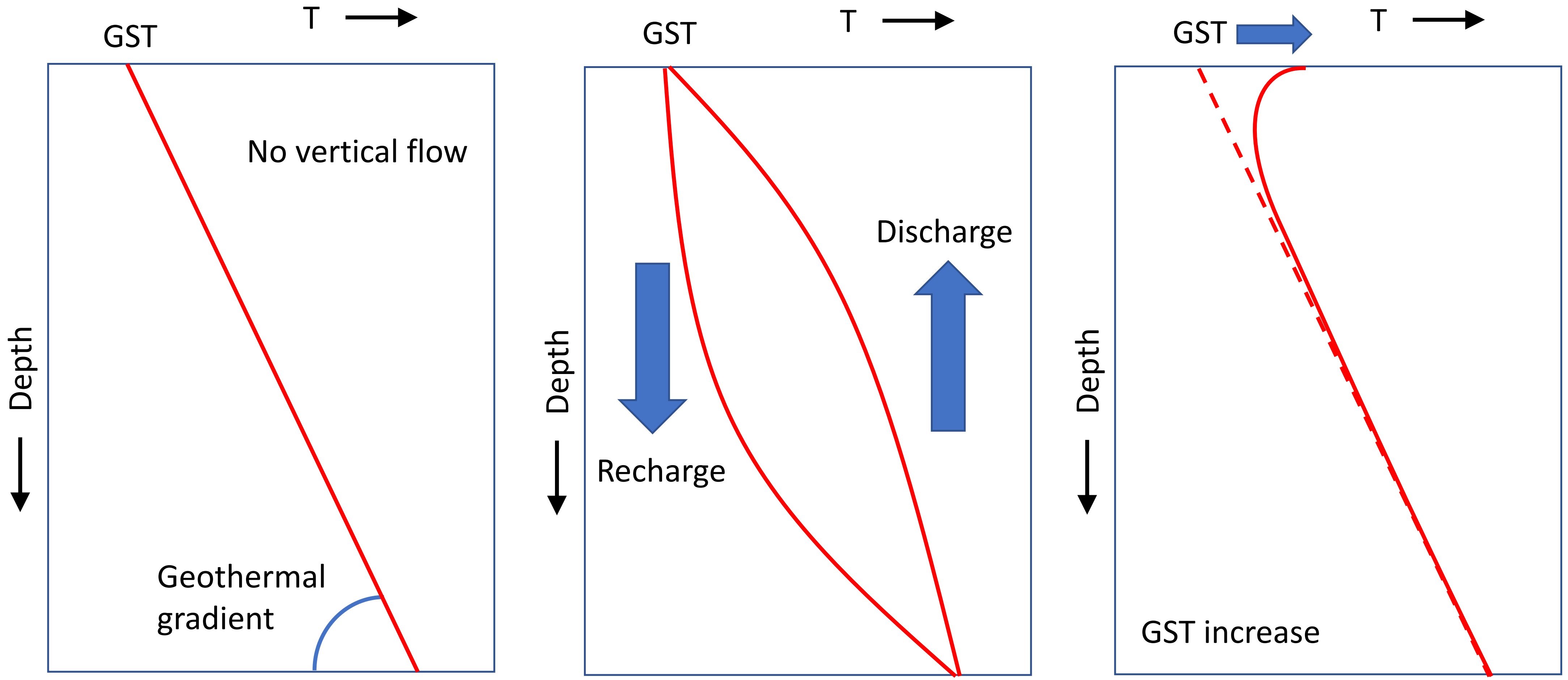
Subsurface and groundwater temperature





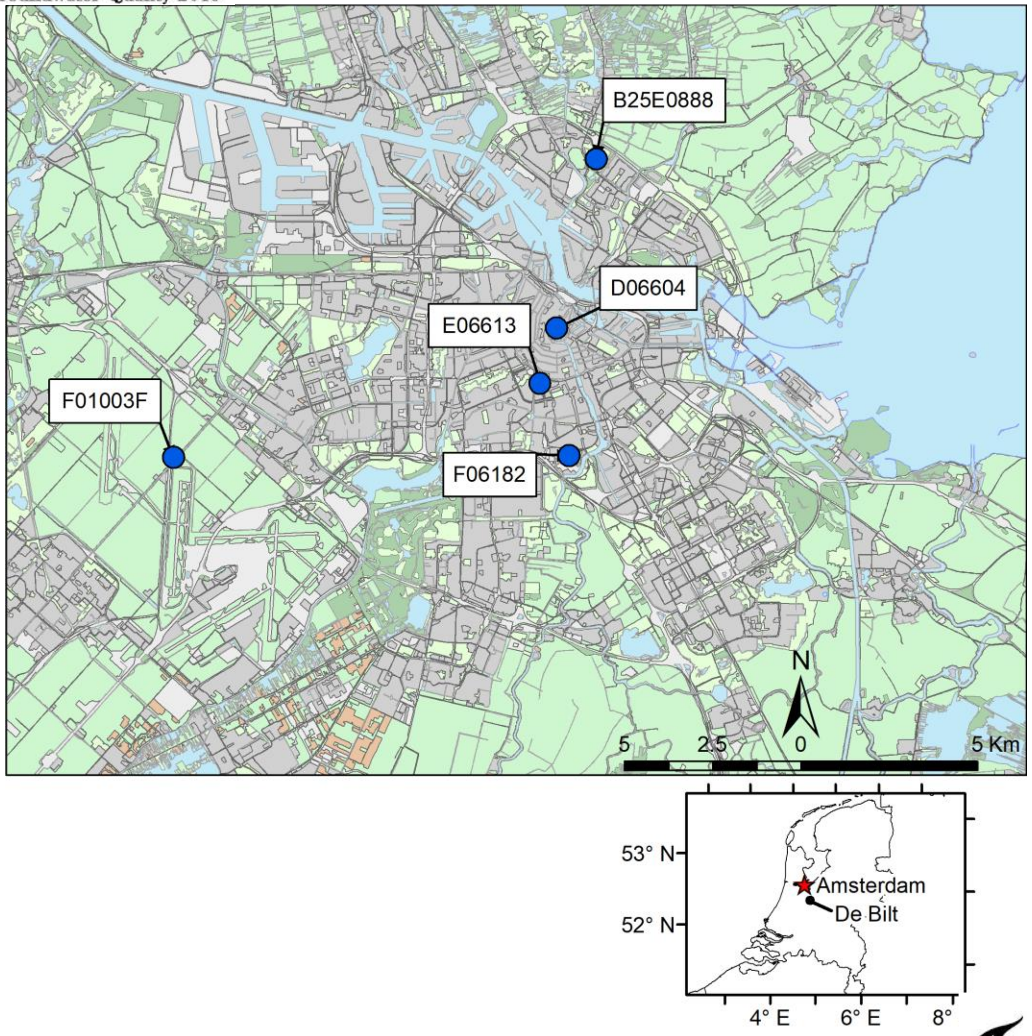
Ranges of 8-16 °C occur in the seasonal zone in rural areas in temperate climates.

Subsurface and groundwater temperature



After Taniguchi et al., 1999).

Subsurface and groundwater temperature

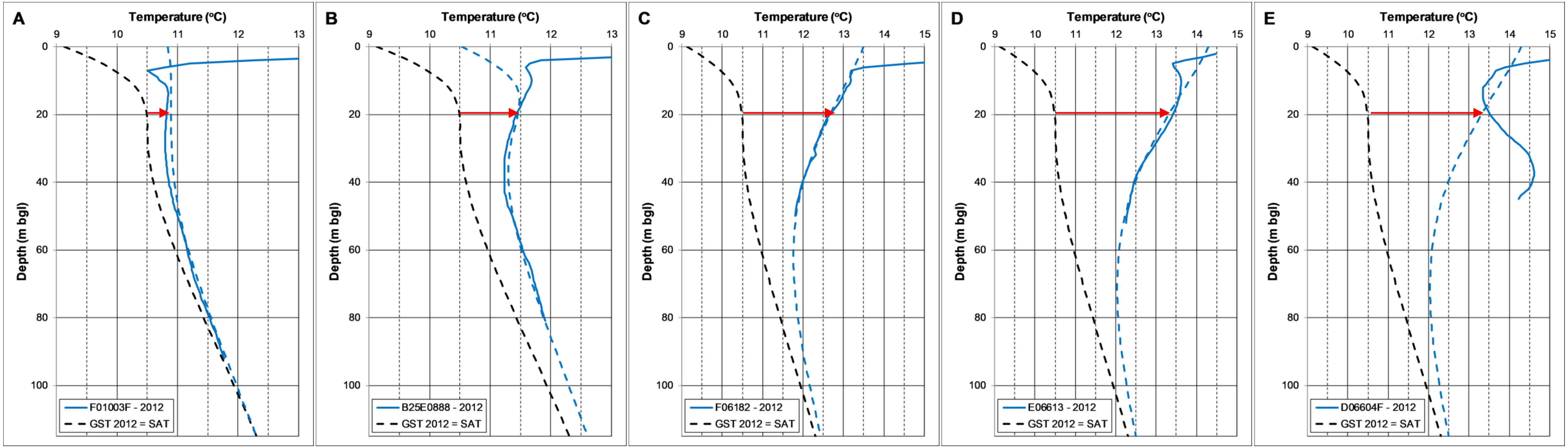


The GST tracks the surface air temperature (SAT) but is systematically higher than SAT depending on land surface conditions (e.g. Mann and Smidt, 2003; Beltrami and Kellman, 2003; Smerdon et al., 2004; Majorowicz et al., 2006; Kooi, 2008).

Climate change, land use change and in particular urbanization result in increased GST values (e.g. Taylor and Heinz, 2009).

Examples from the city of Amsterdam.

Subsurface and groundwater temperature



Meadows, outside the city.
GST-SAT offset = 0.5K

Rural until 1980. Now, parking lot.
GST-SAT offset = 1.4K

Urban, built up between 1964 and 1969. GST-SAT offset since 1970's = 3.2K

Urban, built up since late 19th century. Piezometer in pavement.
GST-SAT offset = 4.0K

City center. Piezometer in pavement.
TD-profile perturbed by UTES system.

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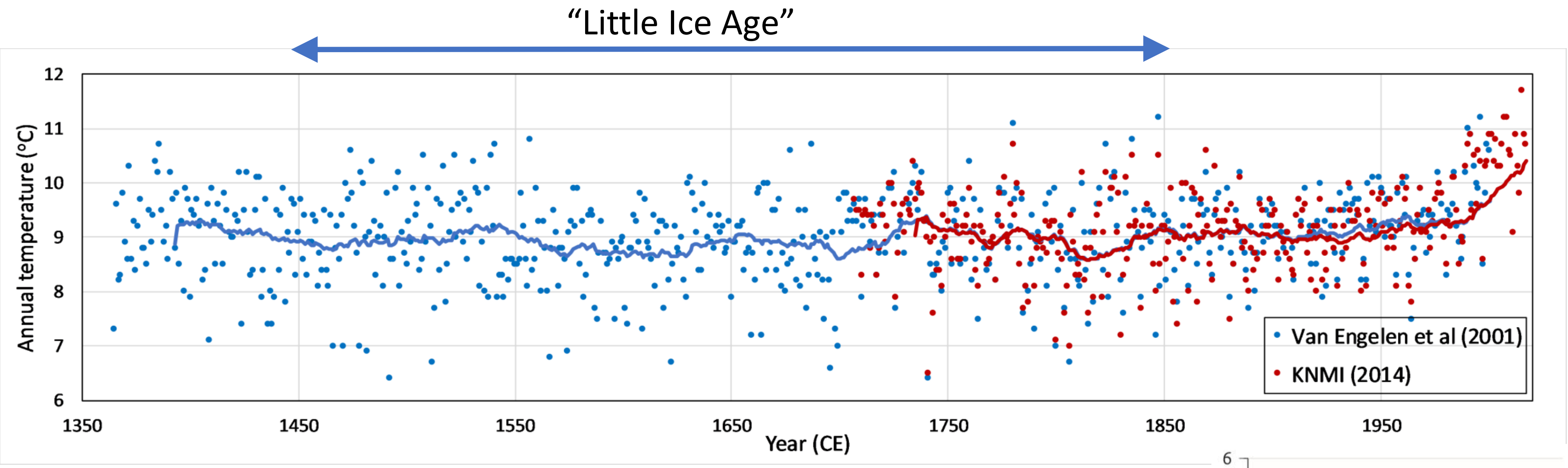
Subsurface and groundwater temperature

In an urban area like the city of Amsterdam, temperatures below the seasonal zone of between 11 and 14^{o}C can be linked to the emplacement of pavements.

The urban heat island and anthropogenic heat sources will further increase these temperatures.

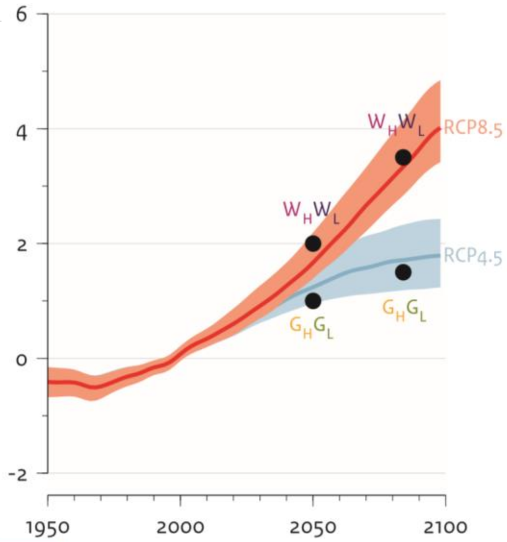
Subsurface and groundwater temperature

Climate past:

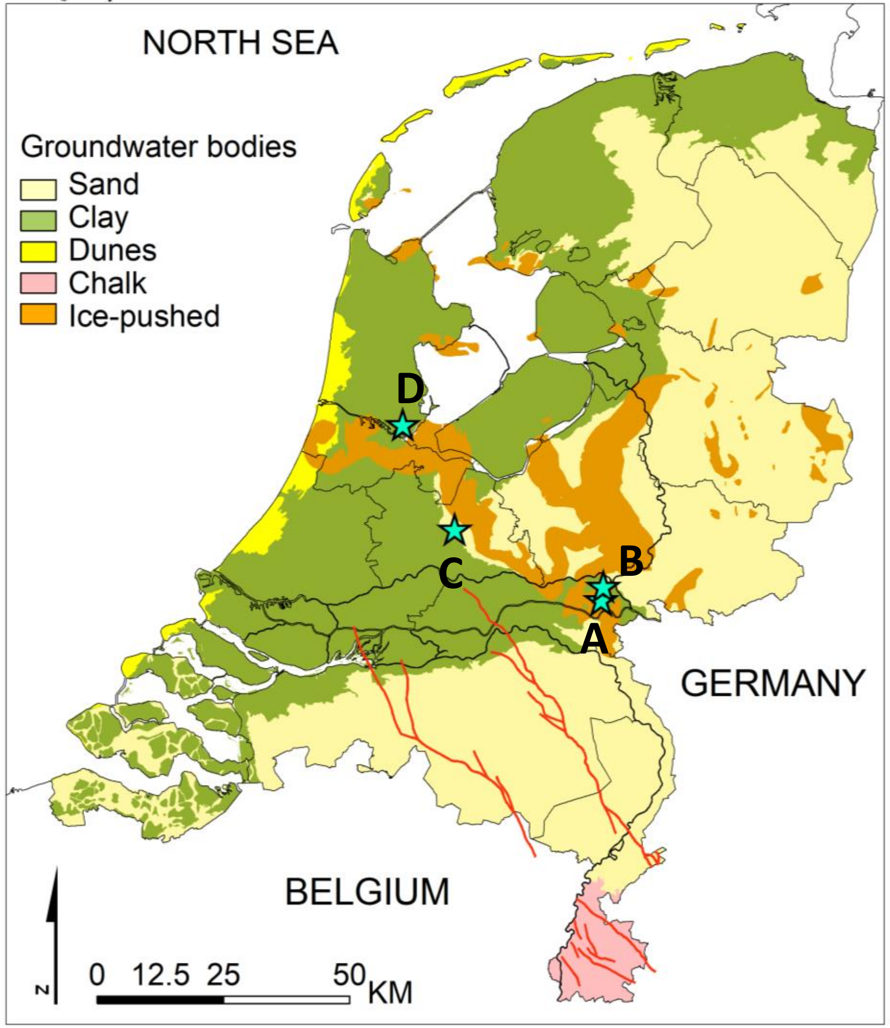


Climate future:
(KNMI, 2014b)

Period	Avg. T [°C]	Climate change scenarios [°C]				
			G_L	G_H	W_L	W_H
1981-2010	10.1					
2030 (2016-2045)		+1.0				
2050 (2036-2065)			+1.0	+1.4	+2.0	+2.3
2085 (2071-2100)			+1.3	+1.7	+3.3	+3.7



Subsurface and groundwater temperature



Examples of repeated TD-profiling at sites where the land cover / land use has not changed the past century.

Subsurface and groundwater temperature

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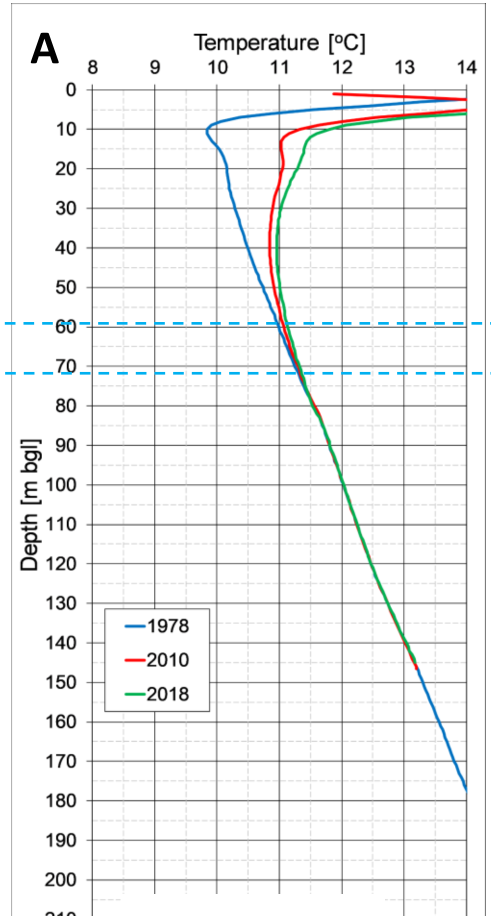
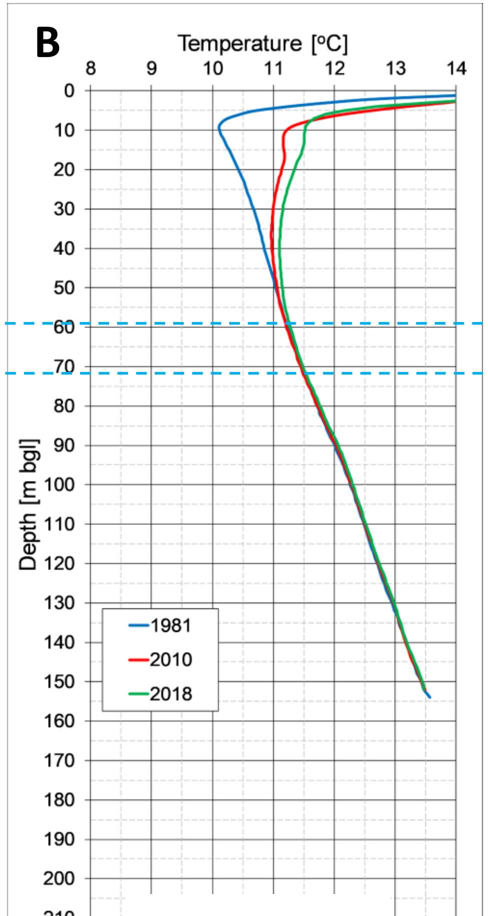
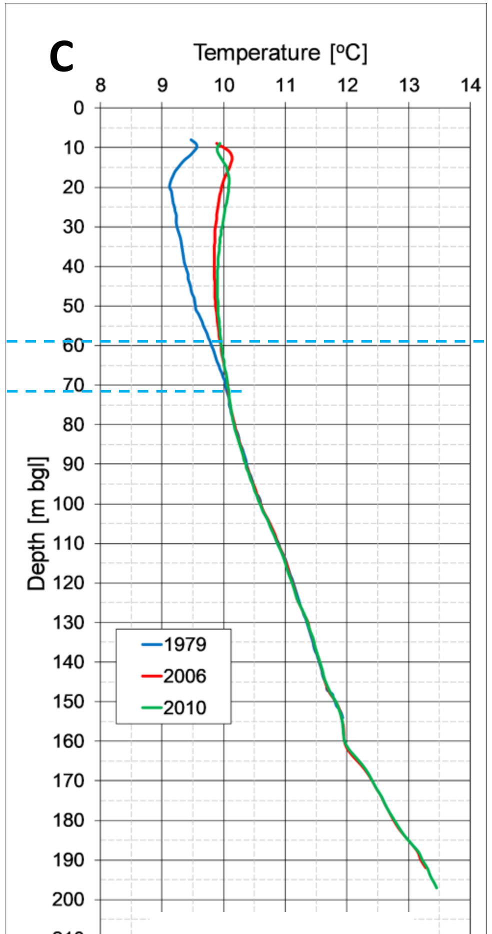
Depth to where T-increase has progressed since 1978/1981 is approx. 60-70 m.



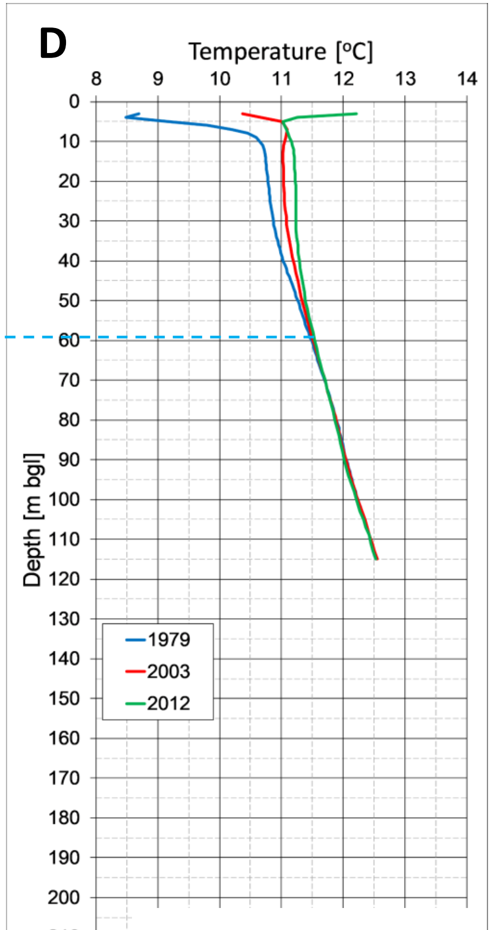
At 20m bgl:
ΔT=1.1 K
0.03 K/a



At 20m bgl:
ΔT=0.9 K
0.02 K/a



At 20m bgl:
ΔT=1.0 K
0.03 K/a



At 20m bgl:
ΔT=0.4 K
0.01 K/a

Temperature increases of 0.1 to 0.3 K per decade.

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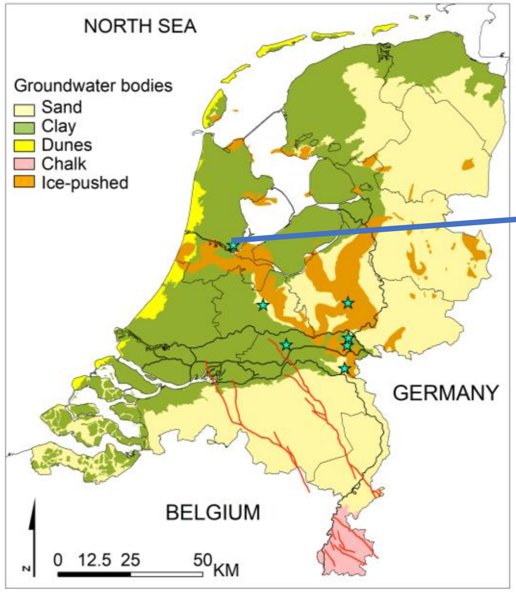
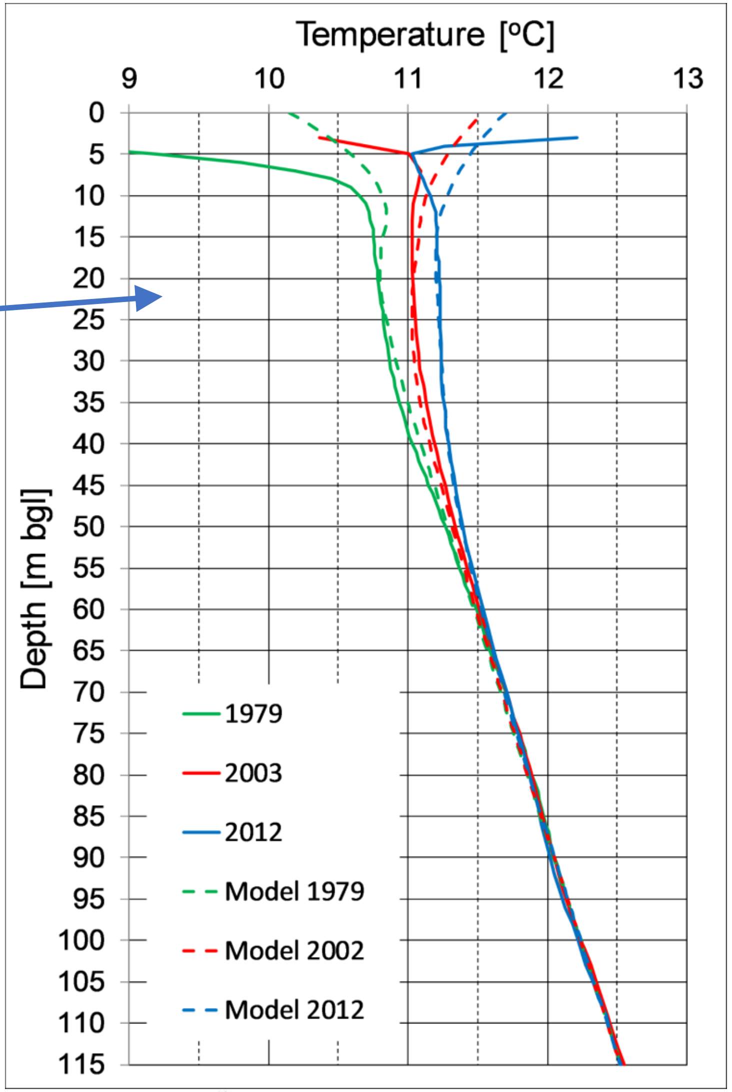
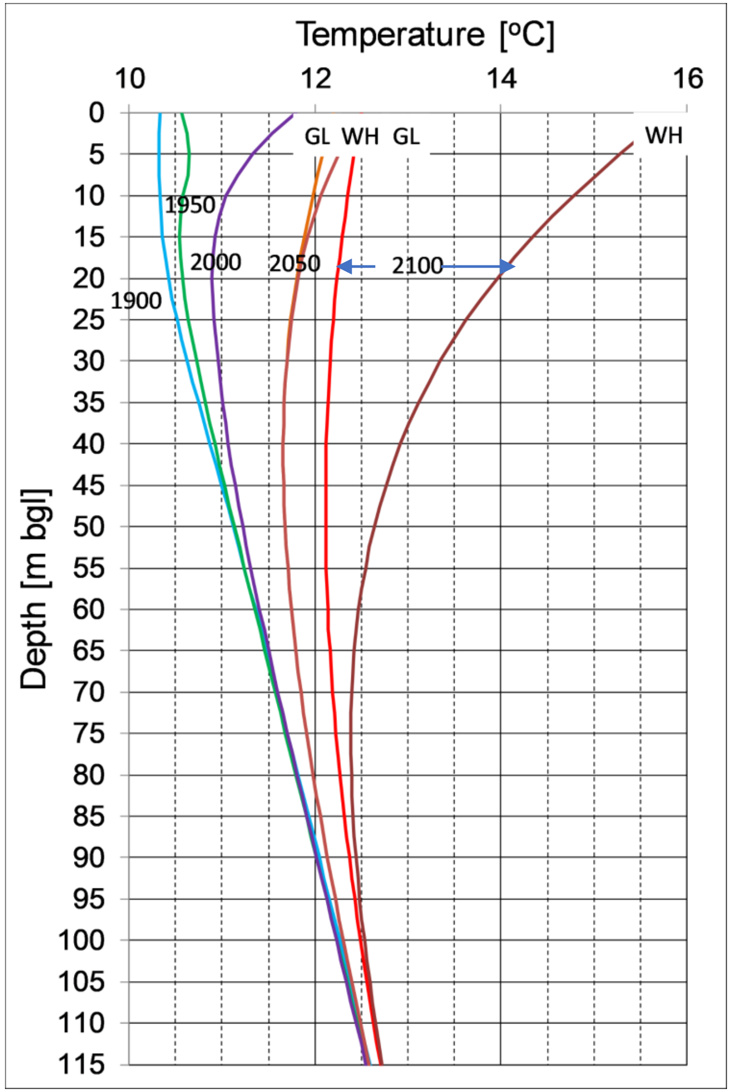
Subsurface and groundwater temperature



Using the model that correctly predicts the 1979, 2002 and 2012 temperatures, projections of the past and future temperatures were made.





Conclusions

- (Repeated) TD-profiling is instrumental in determining past, present and future subsurface temperatures.
- Temperature ranges in the seasonal zone are comparable to those in studies like e.g. Riedel (2019). However, high temperatures are balanced by low temperatures in the following season.
- Land use change (esp. urbanization, pavements) causes GST increase, resulting in an increase of the average temperatures in the seasonal zone. This may cause an 4K average temperature increase near the surface.
- In the examples shown here, climate change has been responsible for temperature increases between 0.4 and 1.1K below the seasonal zone in the past 4 decades. Based on climate scenarios and a (single) synthesized TD-profile, the groundwater temperature at 20m depth may increase from 10.4^{o}C to 11.8 in 2050 to between 12.2 and 14.0^{o}C 2100.
- Therefore, land use change and climate change cause temperatures / temperature changes that fall in the ranges in studies by e.g. Saito et al. (2016) and Riedel (2019). Similar shifts in groundwater composition can be expected.
- However, to quantify the relatively small and long-term effects of land use change and climate change on groundwater quality remains a challenge.

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Thank you for your attention