On the use of geothermal data for climate studies: a case study from Portugal

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Abstract

The study of past climate and climate change in mainland Portugal using geothermal data has started in 1996. Reconstruction of ground surface temperature (GST) history from temperature logs measured in a 200 m deep borehole (TGQC-1), located near the town of Evora in Portugal, indicates warming of 1K since the second half of the nineteenth century to the middle of the 90s of the twentieth century, increasing considerably in the last 10 years. Results of the reconstruction (based on the functional space inversion (FSI) method) are compared with air temperatures recorded at the Lisbon meteorological station since 1856. The series display a warming trend with the amplitude about 1K for the same period. The coupling of the air and ground temperature changes and their downward propagation by heat conduction was confirmed by repeated logging in November 2003, 6.7 years after obtaining the first temperature log.

Introduction

Recent climate changing (warming or cooling) detected in most temperature logs obtained in wells all over the globe is related with changes in the energy budget at the earth's surface which result from an increasing or decreasing of atmospheric temperature. Oscillations of the temperature at the surface of the Earth resulting from climatic changes penetrate into the subsurface with the high frequency components of the temperature signal progressively attenuated as it propagates downwards. As a result the temperature field at depths that range from tens to hundreds of meters contains information on the history of the long-term ground surface temperature. Therefore, under certain conditions (such as, transfer of thermal energy by conduction only, steady-state thermal regime, negligible water flow in the geological formations and no convection near or in the well, and unchanged vegetation cover), precise temperature logs obtained in wells can be used to reconstruct the ground surface history which is related to the climate history in the region of the well (Cermak, 1971; Lachenbruch and Marshall, 1986; Pollack and Chapman, 1993).

Since 1996 there has been an attempt to study the evolution of the past climate in mainland Portugal using temperature logs obtained for geothermal studies. From an initial set of 90 wells that have temperature logs only eigth were chosen as good for estimating ground surface temperature (GST) in the past (Correia and Šafanda, 1999). These wells were logged from 1989 and the depth range of the temperature logs vary between 155 and 485 meters. In this extended abstract we are going to consider only the TGQC-1 well which, since 1997, after being cased, has been used for geothermal studies and, in particular, for GST studies. The TGQC-1 well is located in south-central Portugal at the same latitude as Lisbon.

Method and results

To obtain the ground surface history near the TGQC-1 well the functional space inversion (FSI) method of Shen and Beck (1992) was used. This inversion methodology allows the incorporation of uncertainties in the data as *a priori* standard deviations. The *a priori* geothermal model for the TGQC-1 well was assumed as a homogeneous half-space with thermal properties based on measurements made on rock samples collected from the granitic formations in the region of the well. For thermal conductivity, thermal diffusivity, and radiogenic heat production the values used in the inversion process were 2.8 $Wm^{-1}K^{-1}$, 1.3×10^{-6} m^2s^{-1}, and 2×10^{-6} Wm^{-3}, respectively.

Figure 1 shows the temperature logs obtained in March 1997 and November 2003 in the TGQC-1 well. The difference in the temperatures measured in the two logs is also shown (line in blue). From Fig. 1 it is obvious that there has been an increase in the temperature of the well since 1997, which can be seen for depths as deep as 120 meters. Figure 2 shows the temperature log obtained in 2003 in the same well (curve 1), as well as the steady-state component of the subsurface temperature (dashed line 2) and the reduced temperature (curve 3), which is the difference between the actual temperature log and its steady-state component. Therefore, curve 1 in Fig. 2 is actually a superposition of a steady-state temperature signal with a transient signal which represents the response of the ground to long-term surface temperature changes.

Figure 3 shows the results of applying the FSI method to the transient component of the temperature log obtained in the TGQC-1 well with different levels of noise (curves 1-3) and for the thermal parameters mentioned above for the region of the well. The results of the inversion are also compared with the air temperature measured in the weather station of Lisbon, about 100 km away from the location of the well. The air temperature time series for that weather station, which have started to be collected in 1856, are shown in Fig. 4. The main observation from this figure is that there is an average increase of the air temperature of about 1.1 ºC for the entire period of measurements (about 0.0075 ºC/year) with a noticeable increase of the warming trend after 1970 (about 0.048 ºC/year). In Fig. 3 the relative amplitude of the mean annual temperature is compared with the FSI inversion of the transient component of the temperature log obtained in the TGQC-1 well in November 2003. Even though the fit is not very good, the warming trends in curves 1-3 and curve 4 are similar, in particular in the last 30-40 years.

Much more work is needed to evaluate the climatic change in the territory of mainland Portugal using geothermal data; however, the results presented here are encouraging and further research is thought for the area of the well, in particular, it is planned to install an automatic monitoring system to record temperatures above, at, and below the ground surface to study the air-ground coupling and understand the energy balance at the boundary layer between the ground and the atmosphere.

Conclusions

1. By measuring the temperature in the well TGQC-1 in 1997 and 2003 it is possible to state that the non-linear part of both temperature logs represent a transient component of the subsurface temperature, which has increased in the last years.

2. The air temperature measured since 1856 in the weather station of Lisbon shows an increase of the mean annual air temperature of about 0.0075 ºC/year with an increasing warming trend after 1970 of about 0.048 ºC/year.

3. This same temperature increase is observed in the TGQC-1 well which is located about 100 km away from the Lisbon weather station.

4. The implication of these similar results is that the temperature increase observed in the temperature logs of the TGQC-1 well is a consequence of the long-term air temperature increase.

Acknowledgments

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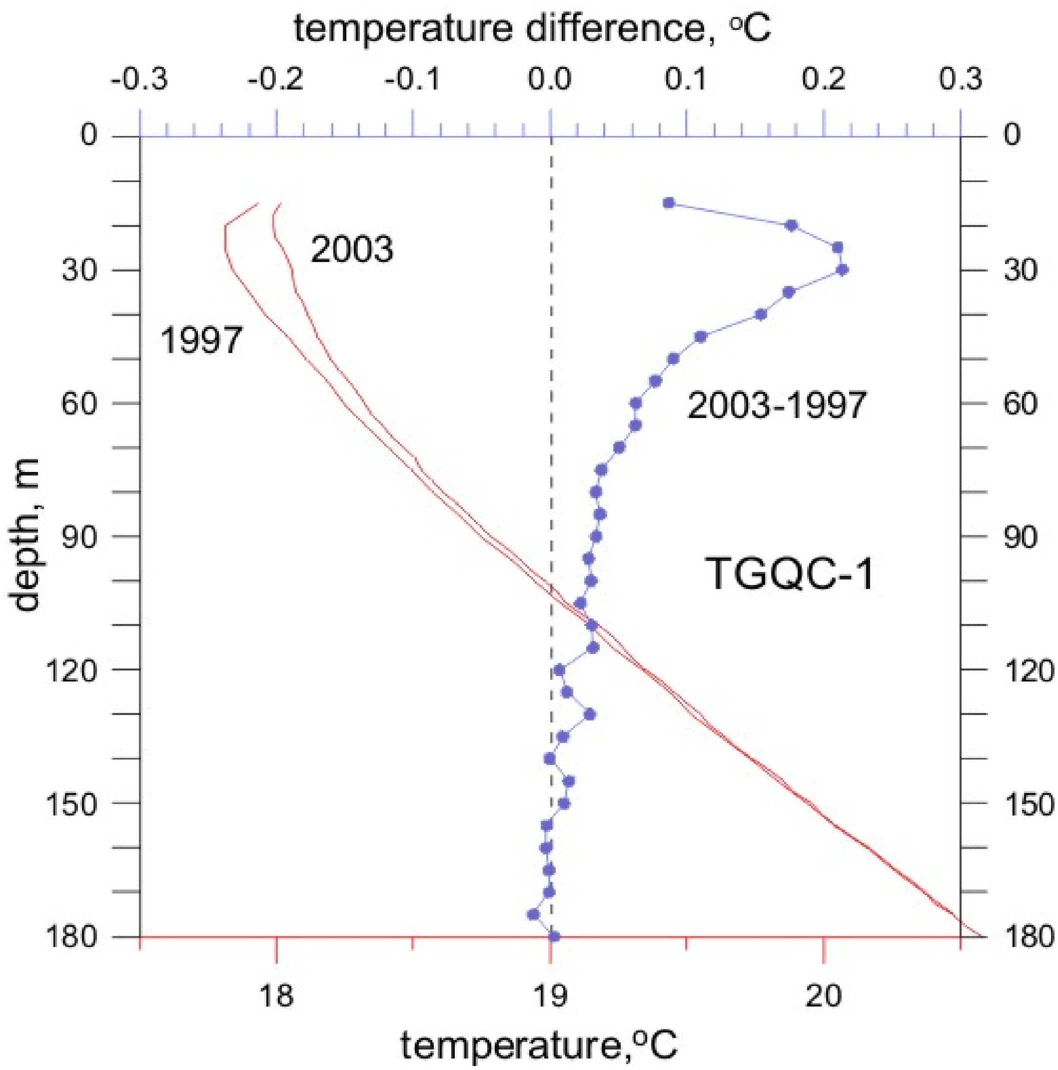

Figure 1 – Temperature logs obtained for two different times (March 1997 and November 2003) for the well TGQC-1. Also seen is the temperature difference between those two logs. Since 1997 there has been an increase of the subsurface temperature.

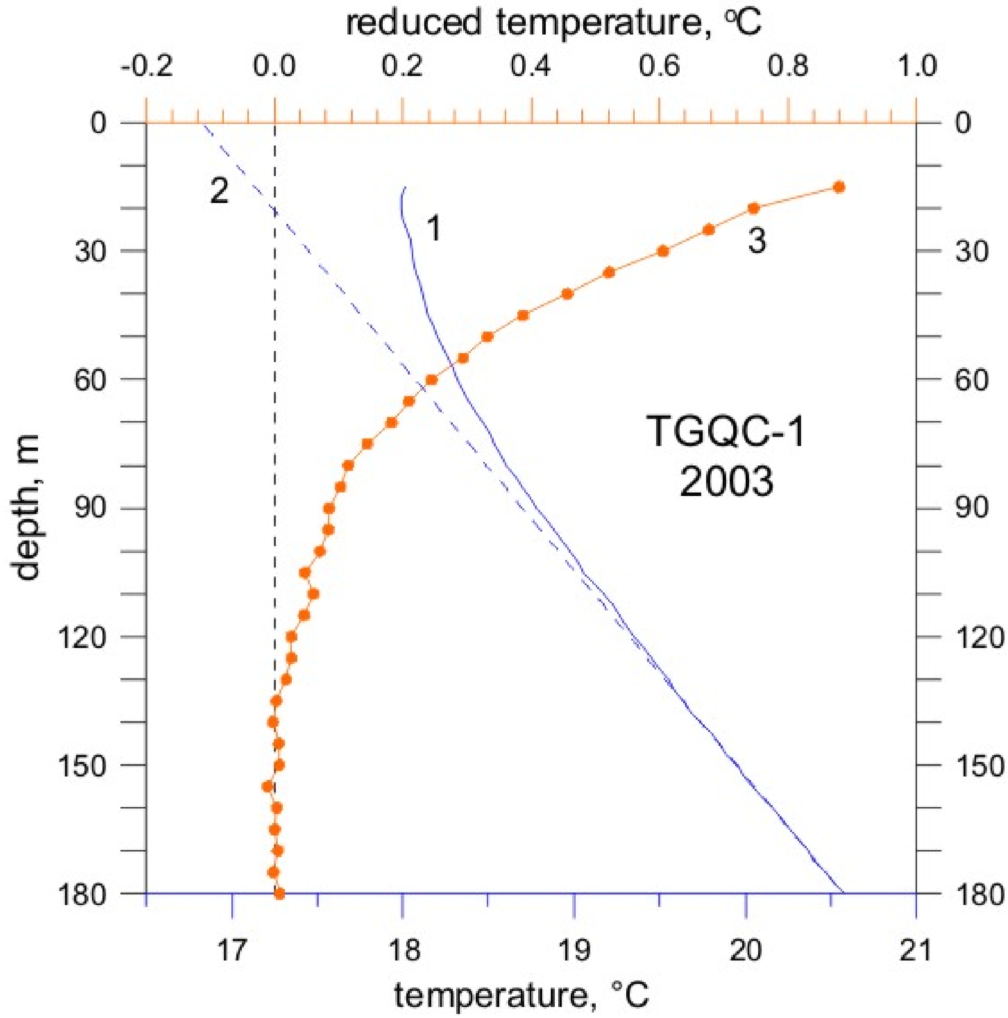

Figure 2 – Curve 1 represents the temperature log obtained in the TGQC-1 well in November 2003; dashed line 2 represents the steady-state temperature for the well, which is calculated by linear fit to the lowermost part of the temperature log; curve 3 represents the reduced temperature, i.e., the difference between the actual temperature log and the linear fit line 2.

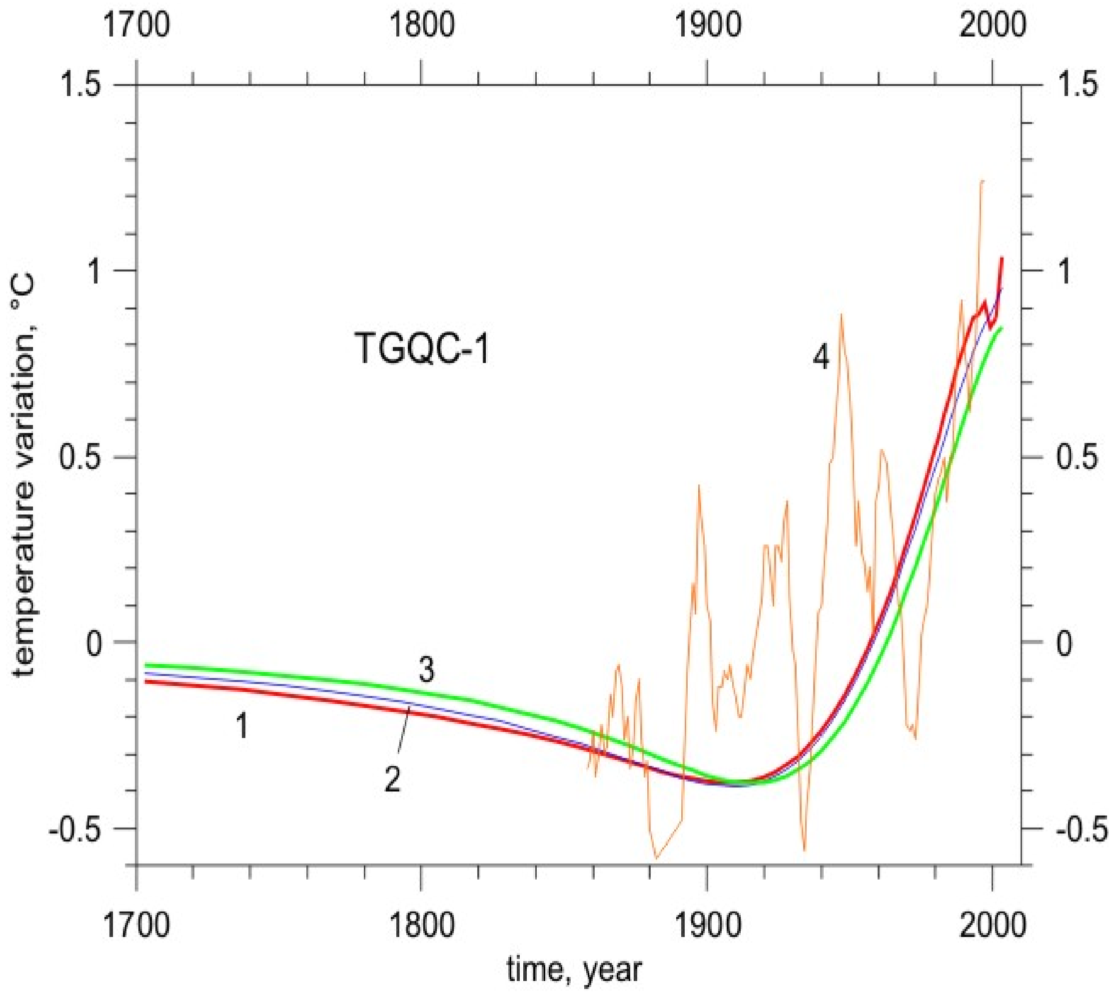

Figure 3 – FSI of the transient component of the temperature log obtained in 2003 in the TGQC-1 well. Curves 1-3 correspond to inversions performed with different levels of noise. Curve 4 represents the amplitude of the mean annual temperature variation since 1856 at the Lisbon weather station (see Fig. 4 for details).

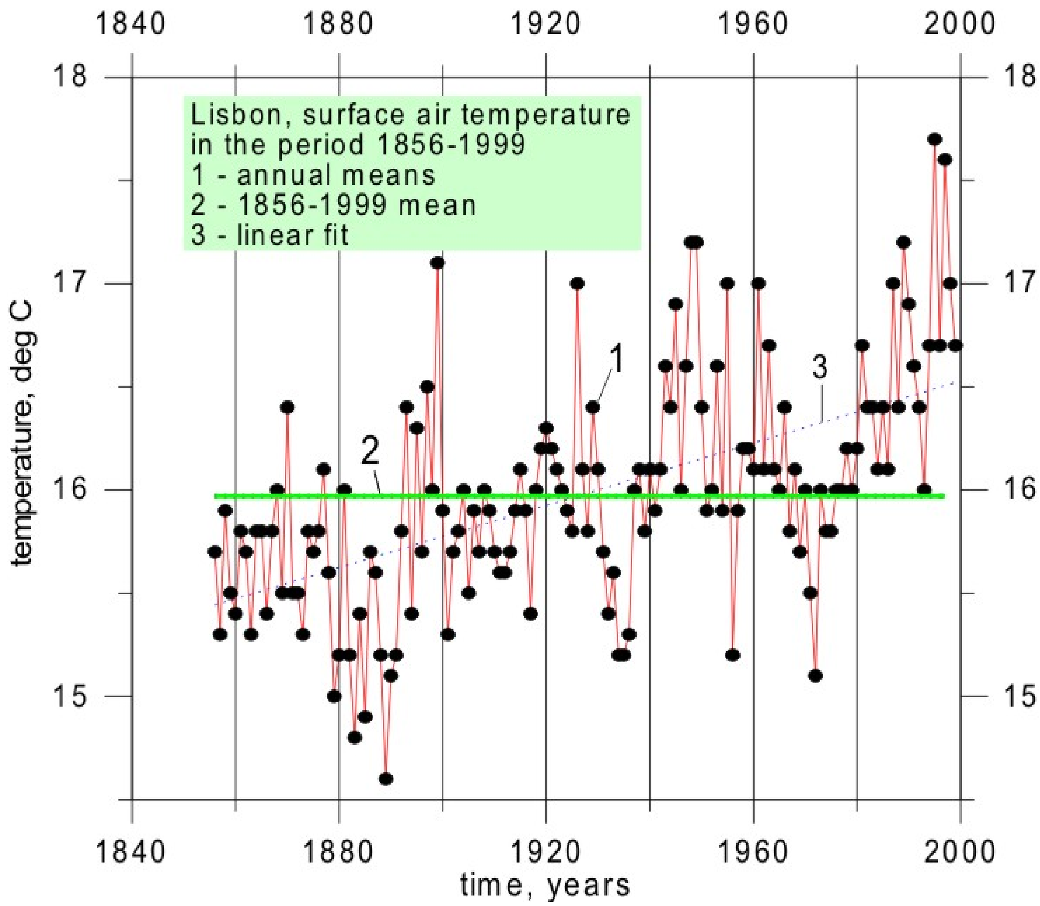

Figure 4 - The GST history at the TGQC-1 site can be compared with the surface air temperatures recorded at the Lisbon weather station during the period 1856-1999 (Leite and Peixoto, 1996). The linear fit to the mean annual air temperatures (curve 3) shows a warming trend of 0.75 ºC/100years, which corresponds to the amplitude of 1.1 ºC since the beginning of the observations.