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# Reconstruction of the thermal environment evolution in urban areas from underground temperature distribution

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ABSTRACT

It is possible to estimate the ground surface temperature (GST) history of the past several hundred years from temperature profiles measured in boreholes because the temporal variation in GST propagates into the subsurface by thermal diffusion. This “geothermal method” of reconstructing GST histories can be applied to studies of thermal environment evolution in urban areas, including the development of “heat islands.” Temperatures in boreholes were logged at 102 sites in Bangkok, Jakarta, Taipei, Seoul and their surrounding areas in 2004 to 2007. The effects of recent surface warming can be recognized in the shapes of most of the obtained temperature profiles. The preliminary results of reconstruction of GST histories through inversion analysis show that GST increased significantly in the last century. Existing temperature profile data for the areas in and around Tokyo and Osaka can also be used to reconstruct GST histories. Because most of these cities are located on alluvial plains in relatively humid areas, it is necessary to use a model with groundwater flow and a layered subsurface structure for reconstruction analysis. Long-term records of subsurface temperatures at multiple depths may demonstrate how the GST variation propagates downward through formations. Time series data provide information on the mechanism of heat transfer (conduction or advection) and the thermal diffusivity. Long-term temperature monitoring has been carried out in a borehole located on the coast of Lake Biwa, Japan. Temperatures at 30 and 40 m below the ground surface were measured for 4 years and 2 years, respectively, with a resolution of 1 mK. The obtained records indicate steady increases at both depths with different rates, which is probably the result of some recent thermal event(s) near the surface. Borehole temperatures have also been monitored at selected sites in Bangkok, Jakarta, and Taiwan.



## 1. Introduction

Temporal variation in the ground surface temperature (GST) propagates into subsurface sediments and basement rocks by thermal diffusion. It is a rather slow process because the thermal diffusivity of sediments and rocks is low, at $10^{-6}$ to $10^{-7}$ $m^2/s$. As a result, GST variation in the last several hundred years has been recorded in the underground temperature distribution in the upper several hundred meters. It is therefore possible to estimate the history of GST, which should be closely related to surface air temperature (SAT), from vertical temperature profiles measured in boreholes (e.g.,

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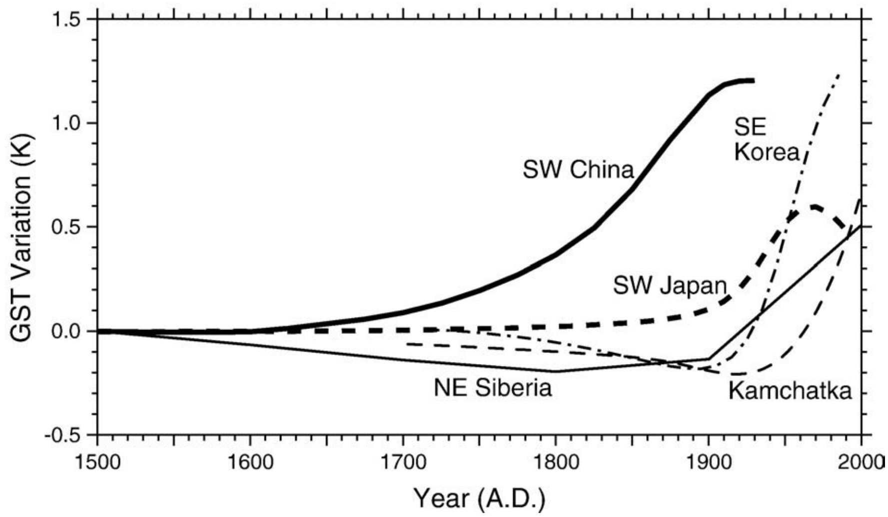


**Fig. 1 – Ground surface temperature (GST) histories reconstructed from borehole temperature profiles in five areas of East Asia (Huang et al., 1995; Pollack et al., 2003; Goto et al., 2005a, 2009; Cermak et al., 2006). Locations of the five areas are shown in Fig. 2.**

Lachenbruch and Marshall, 1986; Wang and Lewis, 1992; Pollack and Huang, 2000). This "geothermal method" for past climate reconstruction has some important features: (1) the temperature history is directly determined from temperature data, not through conversion from proxies such as tree-ring data; (2) the long-term trend (century-scale) of temperature variation is obtained; and (3) times and areas for which no meteorological data are available can be examined. The reconstruction of GST using this method has been conducted extensively since the 1980s, mainly in North America and Europe (e.g., Gosnold et al., 1997; Bodri and Cermak, 1998; Majorowicz et al., 2002), and the analysis techniques have been well investigated (e.g., Shen and Beck, 1991; Wang, 1992; Beltrami and Mareschal, 1995).

GST histories estimated using the geothermal method may reflect both large-scale climate changes, including global warming, and more local phenomena. For examples of GST histories reconstructed from borehole temperature data in five areas of East Asia (Fig. 1; Huang et al., 1995; Pollack et al., 2003; Goto et al., 2005a, 2009; Cermak et al., 2006), a common feature is prominent surface warming in the last 100 to 200 years, which may be partly attributed to global warming, whereas the amplitude and onset time of the temperature increase vary from place to place. These differences may result from local environmental changes, as well as large-scale variation in global warming.

In urban areas, it is expected that the subsurface temperature distribution has been disturbed by various local anthropogenic factors, e.g., the formation of "heat islands," changes in land use, land development for housing and industry, and the pumping of groundwater. Measurements and analyses of borehole temperatures in large cities and their surrounding areas therefore allow the reconstruction of the evolution of the thermal environment near the ground surface associated with the development of cities. Taniguchi et al. (2007) analyzed the average temperature profiles in four large cities in Asia (Tokyo, Osaka, Seoul, and Bangkok) and estimated the amount of recent surface warming and the onset time of warming for each city. Ferguson and Woodbury (2007) examined the subsurface temperature distribution in the city of Winnipeg and revealed that the effect of urbanization on subsurface temperatures is highly variable probably due to difference in land use.

An international multidisciplinary research project "Human Impacts on Urban Subsurface Environments" (termed the "subsurface environment project" below) was started by the Research Institute for Humanity and Nature in 2004 to investigate the effects of human activities on the subsurface environment of large cities in East Asia (Taniguchi et al., 2009-this issue). The primary target cities are Tokyo, Osaka, Bangkok, and Jakarta (Fig. 2). As part of this project, we have been studying the subsurface thermal anomalies in urban areas caused by human activities mainly through measurements of borehole temperature profiles and long-term temperature monitoring. The obtained data are used to reconstruct GST histories in the target areas; these GST histories can be compared with meteorological data and integrated with other information on urbanization processes collected through different approaches. Here, we describe the scope of our studies of thermal processes beneath the ground in the subsurface environment project and present the results obtained in the initial stage, together with those of former related works.

## 2. Method of GST history reconstruction

In large cities in East Asia, which are the target of the subsurface environment project, a number of boreholes have been drilled for various purposes. Of these, wells for groundwater monitoring are generally suitable for measurement of vertical temperature profiles because they are well maintained and basic geological and hydrogeological information on the surroundings is often available. It is necessary to conduct repeated temperature measurements (logging) in such wells at some time interval to examine the stability of the temperature profiles. Logging in boreholes in which temperature profiles