Clim. Past Discuss., 2, S902–S909, 2007
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Climate of the Past Discussions

Interactive comment on "Anthropogenic effects on subsurface temperature in Bangkok" *by* M. Taniguchi

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The comments of Reviewer #1 are very insightful, and useful for the revision process. There are 4 comments, and the following revisions have been made.

Anonymous Referee #1

(1) 1. General Comments This manuscript outlines an attempt to attribute the rise in ground surface temperature in Bangkok as a result of both global climate change and urbanization. This is potentially a valuable contribution to the climate science community because it suggests that it may be possible to gain information on past climates from urban environments, which have traditionally been avoided in subsurface heat flow studies. However, there are several questions that should be answered to establish that the coupling between ground surface temperatures and surface air temperatures in the

study area as these two measurements may or may not be well coupled (Gosnold et al., 1997; Mann and Schmidt, 2003; Nitoui and Beltrami, 2005; Beltrami et al., 2005). Many of these studies have focused on areas with significant snow accumulation or deforestation but they do suggest the need to investigate the relationship between ground surface and surface air temperatures.

Response: As the reviewer mentioned, the difference between ground surface temperature and air temperature is a big issue for the reconstructions. In this paper, we use "reconstruction of the surface temperature (instead of air temperature)". Following the reviewer's comment, I made an additional reference (Nitoiu and Beltrami) on page 3, 2nd para and references.

(2) 2. Specific Comments P. 831, lines 20-25. Anthropogenic effects are clearly important to the temperature distributions beneath urban environments but it has not been established that the urban heat island effect is the same for above and below ground environments. The effect on surface air temperatures is generally considered the sum of microclimatic effects from changes in the radiative balance in built environments (Landsberg, 1981). These effects can be quite variable throughout a city and this could potentially cause sampling problems. Subsurface temperature changes can also be the result of heat losses from buildings (Lachenbruch, 1957; Ferguson and Woodbury, 2004), which will also be quite variable throughout an urban environment. Heat losses from buildings should be a much smaller issue in Thailand than in Canada as considered in the above-mentioned studies but it may still have some effect. Changes in surface cover (Nitoiu and Beltrami, 2005) will perhaps be a much larger issue, as soil temperatures can be altered as a result of land clearing or changing surface cover (e.g. conversion of grassland to pavement). Temperature increases from such changes in land cover can increase soil temperature by a few degrees Celsius over smaller areas and should be considered in this study.

Response: We think that the effect of changes in land cover is a part of urbanization effects. Following the reviewer's comment, we made an additional reference (Nitoiu

CPD
2, S902–S909, 2007

EGU

and Beltrami, 2005) and explanations on page 3, 2nd para and references.

(3) p. 835, line 25-29. The depth by 0.1 C apart does provide an interesting metric of the importance of surface forcing on subsurface temperatures. However, it appears to be arbitrary and its use should be justified.

Response: In Bangkok, some boreholes show minimum temperature at the surface (not below the surface). Therefore to demonstrate the effect of surface warming without "the depth with minimum temperature", "the depth apart by 0.1 ℃ from the geothermal gradient" is introduced in this paper. Additional explanations with the sensitivity of "the depth" have been made on page 8, 1st para.

(4) p. 835, lines 17 to 21 and Section 4 (pp. 836-837). The rapid development since WWII does suggest that this may be the overall onset of the urban heat island effect but the timing of this event may be significantly different than a linear increase for the entire city with different magnitudes of increase. Many of the effects related to changes in radiative balances and conductive heat flow from buildings will have immediate effects and behave more like a step function or exponential increase in early times rather than a linear increase (Ferguson and Woodbury, 2004; Nitoiu and Beltrami, 2005). Also, if areas at increasing distance from the city centre were developed at later times, the onset of warming related to urbanization should take place at a later time. This may also explain the exponential relationship between the distance from city centre and depth to 0.1 C apart in the borehole. Consideration of this idea could lead to the conclusion that the surface warming is greater in the fringe areas of the city than the analysis produce in this paper suggests. Rather than focusing on relationship of depth to 0.1 C apart from steady state and distance from city centre, this paper would make a much stronger argument if individual temperature profiles were considered. If attempts were made to model each profile using different magnitudes, rates and onsets of warming considered along with the statistical fits of these various models, the findings of this study would provide a more complete understanding of the usefulness of subsurface temperatures in urban environments.

CPD
2, S902–S909, 2007

EGU

Response: Regarding the non-linearity of air temperature, step function or exponential increase could be possible, however, the linear increase can be used as a first order assumption. In this study, I used “forward” calculations by uses of air temperature to evaluate the effects on subsurface temperature. Although the “inverse” calculations by uses of subsurface temperature to reconstruct the changes in surface temperature could be possible, and the comparisons between “forward” and “inverse” methods may be future works. I made an additional explanation on page 6, 1st para, and page 11 1st para.

The comments of Reviewer #2 are very insightful, and useful for the revision process. There are 7 comments, and the following revisions have been made.

Anonymous Referee #2 (1). General comments In this paper, the magnitude of surface warming was estimated based on the subsurface temperatures (actually groundwater temperatures) in Bangkok and extent of thermal effect due to urbanization (heat island effect) was also calculated. Theme of this paper is of value for international readership and rationale of the paper is clear and sound. But the authors should answer some important questions and issues (see specific comments) and they should improve English of the paper prior to final publication.

Response: Following the reviewer’s comment, I made additional explanations as follows, and got help from a native speaker for the English.

(2) 2. Specific comments, Page 834, lines 8-10: The author said “the logged boreholes are cased and thus the water temperatures in boreholes represent the temperature of groundwater surrounding the boreholes.” The referee does not understand it. Because the boreholes were cased (nearly fully or partly??), the water temperatures cannot represent those of ambient groundwaters. At least to the depth of the first open interval (top of well screen or top of uncased interval), the groundwaters in the boreholes would be stagnant. Thus the water temperatures within this interval may be significantly and directly affected by the outdoor air temperature. To clearly address this problem,

CPD
2, S902–S909, 2007

the author should add some more explanations on borehole completions (well depth, casing interval, screen interval, groundwater use or not use for any purpose) and hydrogeologic conditions (water levels, geology, hydraulic conductivity).

Response: Following the reviewer's comment, I made additional references (Dapaah-Siakwan and Kayane, 1999; Krige, 1939) and explanations on free convection on page 4, last para

(3) Page 835, lines 26-29: What is your reasoning in selecting 0.1oC, not 0.2 oC, 0.3 oC or else?

Response: In Bangkok, some boreholes show minimum temperature at the surface (not below the surface). Therefore to demonstrate the effect of surface warming without "the depth with minimum temperature", "the depth apart by 0.1 ℃ from the geothermal gradient" is introduced in this paper. Additional explanations with he sensitivity of "the depth" have been made on page 8, 1st para. As same as #1-3

(4) Page 836, lines 22-23: The referee also thinks that the population density may not represent the additional urban heat. Is there any study result supporting your statement that the change in population can be used as a first order factor of the heat island effect? Is the population density for dwellers (residents) or daytime workers? In metropolitan cities, the two populations are very different.

Response: As reviewer mentioned, population is not only the factor for heat island, however, it is one of major driving force for the heat island effect. We do not have a data of daytime workers and nighttime population, however we may use population as the first order assumption. Following the reviewer's comment, I made additional explanations on page 7, 2nd para

(5) Page 842, Fig. 3: The referee thinks that so called "global warming" will affect air temperatures in suburban areas as well as in urban areas. However, according to your figure, there was practically no increasing trend of the air tem-

CPD

2, S902–S909, 2007

peratures in the suburban area (B), which is 120 km north of the city center. Thus increase of the air temperature at A may be entirely attributed to urban effect (not combined effect of global warming and urbanization).

Response: It may be able to separate both urbanization and global warming effects by comparing the results with global meteorological studies (Kalnay and Cai, 2003; Kalnay et al., 2006; Lim et al., 2005), however we certainly need additional future works. Following the reviewer's comment, I made additional explanations on page 11, 1st para

(6) Page 844, Fig. 5: The fitting curve appeared seemingly reasonable and the determination coefficient is rather high. But there are no data points at distances 50-120 km. Only single value was used for remote area. For more reliable estimation, values for intermediate distances are essentially required.

Response: Unfortunately, there was no accessible boreholes which is suitable for this study between 50-120 km. Following the reviewer's comment, I made additional explanations on page 8, 1st para

(7) 3. Technical corrections 1) Page 832, line 10: depending on->with 2) Page 832, line 11: insert "thermal" between "the" and "expansion" 3) Page 833, line 2: 1948,->1948;, 1986,->1986;, 1993,->1993;, 1995,->1995;, 1998,->1998;, 2000,->2000; 4) Page 834, line 23: 1999,->1999; delete "and" 5) Page 836, line 12: whichv->which v 6) Page 838, line 3: expansion->thermal effect 7) Page 839, line 14: Climate->climate 8) Page 839, lines 17-18: Change->change, Record->record, Subsurface->subsurface, Temperature->temperature, Global->global, Perspective->perspective

Response: Following the reviewer's comment, I made corrections

The comments of Reviewer #3 are very insightful, and useful for the revision process. There are 2 comments, and the following revisions have been made.

Anonymous Referee #3 (1) Temperature was measured in boreholes of 10 cm - 30 cm

CPD

2, S902–S909, 2007

diameter and the author claims that thermal free convection does not occur here and can be neglected. Free convection effects were studied in detail in the past by Diment (Geophysics, 32(4), 720-726, 1967) and Gretener (Geo-physics,32(4), 727-738, 1967). In most boreholes with diameters of 10 cm or more free convection was observed with amplitudes between several mK and 80 mK. A critical gradient can be given for the onset of free thermal convection as a function of absolute temperature, gravity, several material properties (such as thermal expansion, viscosity, thermal diffusivity, spec. heat capacity) and geometric properties of the borehole (such as diameter). For a borehole diameter of 13 cm, Gretener arrives at a critical temperature gradient as little as 1 K/km for water at 43 _C. Since temperature is in the numerator of the corresponding expression, lower temperatures, as measured in Bangkok, yield accordingly even lower values. In view of this, I am almost certain, that there is free convection in the boreholes measured in Bangkok. This effect is often overlooked when a borehole is logged a a certain speed. In point-by-point measurements the oscillations can be easily observed with periods varying from several minutes to even hours, depending on borehole diameter. I suggest the author inspects the data again in view of the critical gradients for the onset of free convection and discusses possible amplitudes. A certain roughness in the logs may serve as an indicator. I feel this effect needs to be discussed in sufficient detail in order to warrant further discussion of small temperature deviations ("0.1 _C apart from the steady-state profile).

Response: Following the reviewer's comment, I made additional references (Dapaah-Siakwan and Kayane, 1999; Krige, 1939) and explanations on free convection on page 4, last para As same as #2-2

(2) This leads to my second point: The author calculates theoretical vertical temperature profiles allowing for vertical heat advection by groundwater flow. Here again, a discussion of the effect of regional flow systems (which are not vertical everywhere) on the observed temperatures is necessary, in particular because the author defines as a criterion for the influence of the urban heating effect a 100 mK deviation of the

CPD
2, S902–S909, 2007

EGU

measured profile from the theoretical prediction. Incidentally, the original wording for the criterion ("the depth apart by 0.1 _C from the steady thermal gradient") is a bit awkward and prone to misunderstanding. Maybe it can be rephrased to make it more simple and easier to understand. At any rate, this approach really requires a discussion of errors. These may be induced by variations in soil properties and Darcy flow rates plugged into equation (1), but also by free thermal convection effects which were observed in holes of 15 cm and 25 cm diameter with amplitudes as large as 80 mK by Gretener (1967). All in all, I think this interesting approach merits additional work invested in the discussion of data quality and sources and size of errors. In a revised form, the m/s would be of interest to a much larger group of readers.

Response: There is a difference of temperature-depth profile between groundwater recharge area and discharge area due to vertical flow, as well as horizontal flow effects. However, the thermal convection which is a product of groundwater flow rate and thermal gradient is usually smaller in horizontal than vertical (Taniguchi et al., 1999), because of negligible horizontal thermal gradient. Moreover, the effect of vertical flow in this study area is negligible (Sanford and Buapeng (1996), therefore we may calculate the surface warming effect without groundwater flow effect as first order assumption. Following the reviewer's comment, we made additional reference and explanations on page 9, 1st para.

Interactive comment on Clim. Past Discuss., 2, 831, 2006.