# PRELIMINARY ANALYSIS OF TWO-YEAR LONG RECORDS OF AIR AND UNDERGROUND TEMPERATURES AS MEASURED AT AUTOMATIC WEATHER STATIONS IN ROMANIA

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*Analyse préliminaire des enregistrements de température de l'air et du sol par les stationes météorologiques automatiques en Roumanie.* Données de température, enregistrées en 2002 et 2003 dans 10 des 70 stations du Réseau météorologique automatique roumain, sont présentées et analysées en termes de chaleur transférée de l'air au sou-sol. La température de l'air (2 m) et celle à 0, 5, 10, 20, 50 et 100 cm sous la surface du sol ont été monitorisées. Les stations ont été choisies de façon de représenter les principaux zones climatiques de la Roumanie. Les modélisations confirment que pour certains intervalles de temps et certains emplacements les températures dans le sol suivent la température de l'air et par conséquent le transfert de chaleur se fait par conduction, tandis que pour les autres processus, comme la gelée du sol ou le chauffage, la radiation solaire jouent un rôle important à l'interface air-sol. La différence moyenne entre la température de l'air (2 m) et celle à la surface pour les stations individuelles varie entre 0,52 K et 1,66 K; la différence moyenne pour les 10 stations est 1,07 K.

*Key words*: temperature, air, soil, automatic station, Romania.

## INTRODUCTION

Reconstruction of past climate changes from geothermal data has proven, in the last decade, to be an additional source of information to complement meteorological and proxy records of climatic change (Harris and Chapman, 1998; Şerban *et al*., 2001; Pollack and Smerdon, 2004, Beltrami *et al*., 2005). The interest in this method lies in the fact that it examines a direct measure of temperature, free of problems such as variable standards found in meteorological and proxy data. Unlike proxy records, it has a very clear physical interpretation (*i.e.* temperature).

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However, although the Earth's response to the energy transfer at the surface is related to the surface air temperature, the temperature in the ground is an integral of the effects of air temperature variation, vegetation and snow cover variations, phase changes and solar radiation changes at the ground surface (Oke, 1987; Beltrami and Kellman, 2003).

The setting up of a new automatic weather station network in Romania in the last few years is likely to produce a homogeneous data set for a territory characterized by lateral climatic variability (Boroneanţ *et al.*, 2004) that can be used in clarifying some of the aspects of the heat transfer at the Earth's surface. A preliminary attempt is reported in the present paper.

## DATA

The National Meteorological Administration network comprises 70 automatic weather stations evenly distributed over the country. Each station is equipped with MAWS 301 Vaisala measuring systems that are designed to measure the atmospheric pressure, air temperature, relative humidity, wind speed and direction, liquid precipitations, as well as global, net and diffuse radiation. At mountain weather stations an ultrasonic device is used to measure the snow depth and at the low altitude stations, the soil temperature is measured using a QMT 107 system. The accuracy of the air and soil temperature records is better than ± 0.2 K.

In this study, air (2 m) and soil temperature at six depth levels (0, 5, 10, 20, 50, 100 cm) recorded by 10 of the Romanian automatic weather station network (Fig. 1), in 2002 and 2003, have been used.

As an example, the daily-averaged temperatures recorded at Bistriţa are illustrated in Fig. 2. One can easily see the attenuation of the high frequency temperature fluctuations and the attenuation of the annual variation as the signal is propagated into the ground, the phase shift with depth of the temperature wave, as well as the heat valve effect (in summer the heat flows downwards, while in winter the heat flows toward the Earth surface) (Beltrami, 2001) and the zero curtain effect (negative temperatures cannot be found in the ground until the water in the soil completely freezes) (Kane *et al.*, 2001).

## ON THE HEAT TRANSFER REGIME IN THE SUBSURFACE

We examined the character of the heat transfer regime in the subsurface (1) by analyzing perpendicular superposition of temperature records at various depths, and (2) by looking at the fit between the soil temperatures simulated with a simple conduction model and the measured data.

In Fig. 3 the measured air temperatures at Bistriţa in 2003 are compared with the soil temperatures recorded at various levels (see figure caption) and in Fig. 4 the soil temperatures at 10 cm are compared with the deeper temperature series. In

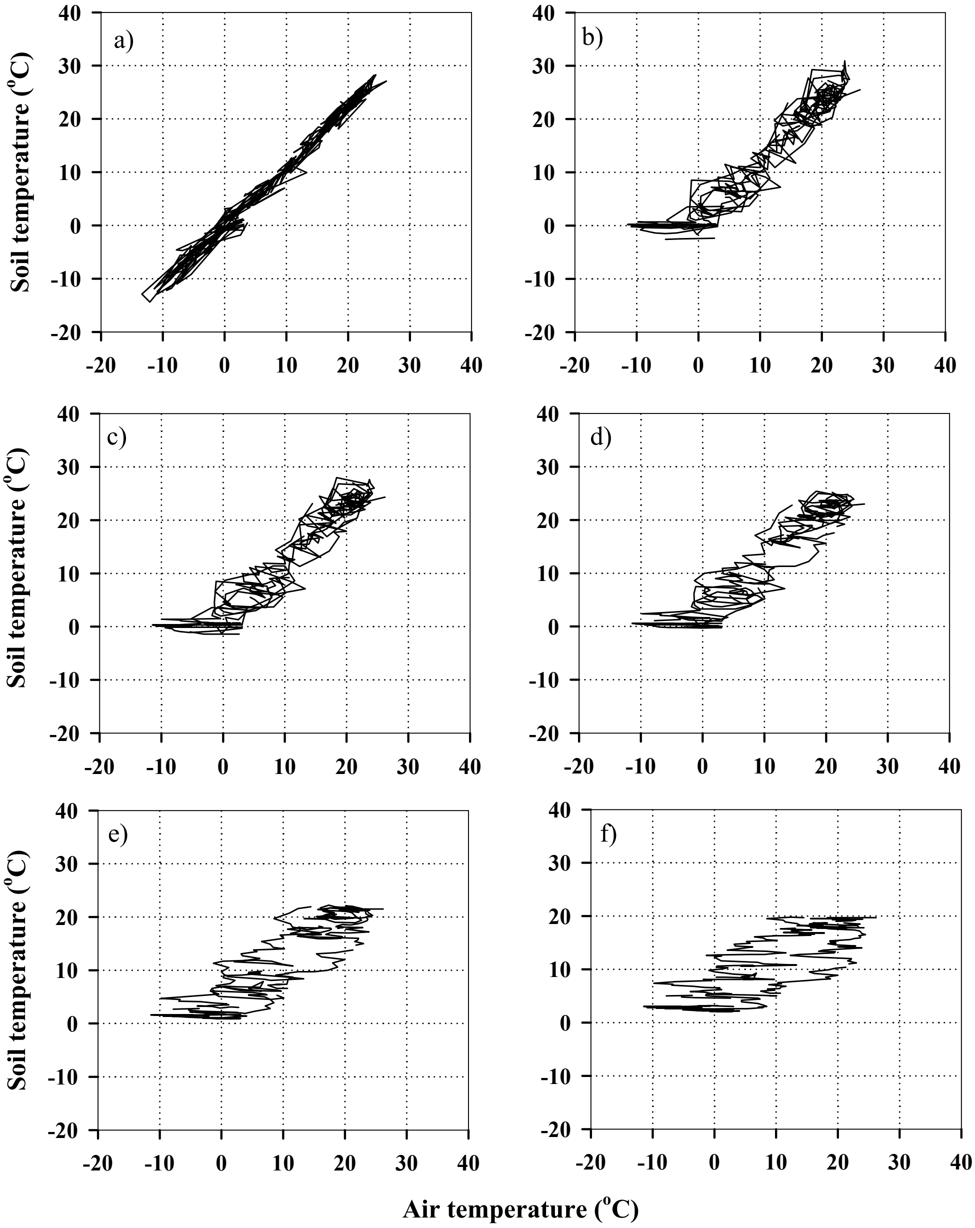


Fig. 3 – Perpendicular superposition of air temperatures and a) soil surface, b) 5 cm, c) 10 cm, d) 20 cm, e) 50 cm, f) 100 cm temperature series measured at Bistrița station in 2003.

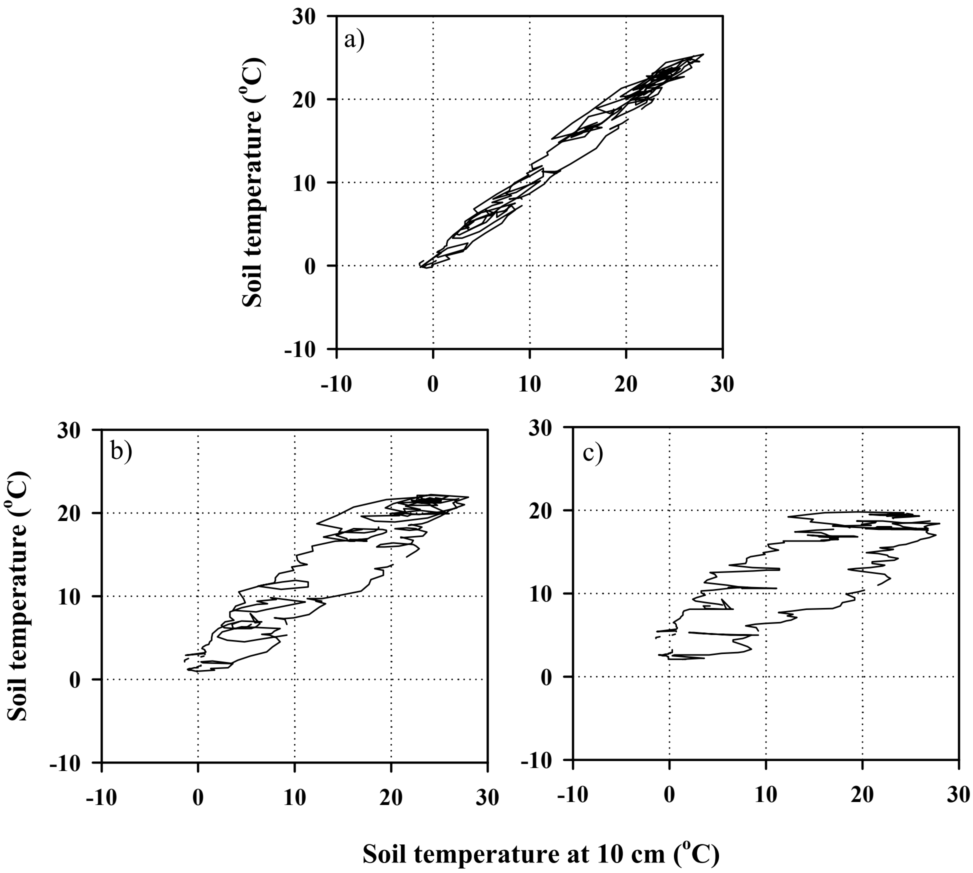


Fig. 4 – Perpendicular superposition between the 10 cm soil temperature and the soil temperature measured at a) 20 cm, b) 50 cm and c) 100 cm, for the year 2003, Bistrița station.

ideal conductive conditions the plots should be ellipses with their long axes becoming smaller as one goes deeper into the ground, because of the attenuation with depth of the annual signal amplitude, and with their short axes becoming larger, due to phase difference between temperatures recorded at different levels (Beltrami, 1996). This behavior is recognizable in the plots, but is strongly disturbed by shorter-term fluctuations and by nonconductive heat transfer at the air-soil interface. The latter is apparent from the flattening of the interception figures around the freezing point and from the high variability during summer (the maze from the upper part of the interception figures) due to direct solar insulation, the station being located in open. The short term oscillations are reduced when analyzing the heat transfer within soil, between 10 cm and 20 cm, 50 cm and 100 cm respectively (Fig. 4). The extremely low thermal diffusivity of the upper part of the soil (Niţoiu and Beltrami, 2005) filters out the high frequency temperature variations. Figure 4 clearly shows that during winter the soil temperature below 20 cm is above the freezing point, thus non-conductive effects associated with the latent heat of melting and freezing of the liquid present within soil pores do not appear anymore to be superimposed on the process of heat transfer through conduction. Even though below 50 cm several short term temperature fluctuations are still visible, the conduction is the main mechanism of heat propagation to the underground (see Fig. 5).

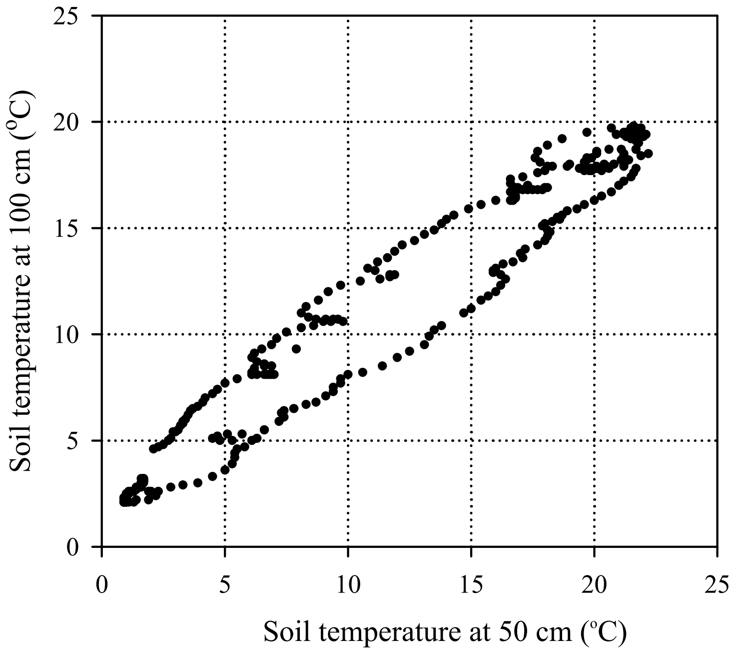


Fig. 5 – Perpendicular superposition of 50 and 100 cm soil temperatures recorded at Bistriţa in 2003.

In an ideal conductive subsurface, variations of surface temperature are propagated into the ground according to the one-dimensional heat conduction equation (Carslaw and Jaeger, 1959)

$$\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2}, \tag{1}$$

where $T$ is temperature, $k$ is thermal diffusivity, $t$ is time and $z$ is depth.

A forward modeling of temperature variations at a given depth induced by temperature variations at surface would show, when compared to actual recorded temperatures, if the transfer of heat is by conduction or other processes are present too. Taking as a forcing function the surface soil temperature variation with respect to the first day of data (January 26th 2003), we generated the 5 cm soil temperature variation assuming different values for the soil thermal diffusivity ranging from $0.1\cdot 10^{-6} m^2 s^{-1}$ to $0.5\cdot 10^{-6} m^2 s^{-1}$ (see Fig. 6). Whatever thermal diffusivity value is used, the pure conduction model is not able to reproduce the actual temperatures recorded over an entire year interval. The discrepancy is large in winter and summer, when processes such as freezing or, respectively, evaporation of the water content imply convection and latent heat contribution. Differences between modeled and measured temperatures may also appear from the seasonal variation of the effective thermal diffusivity of the first meter of the soil.

Taking as a forcing function the 50 cm soil temperature variation with respect to the measured value on February 6th 2003 (there are missing data in January due to recording system mal-function), we generated the soil temperature variation at 100 cm for the year 2003, using different values for thermal diffusivity, and we compared the modeled temperatures with the measured ones. The results are illustrated in Fig. 7 where it can be seen that for this depth interval the best fit (root mean square (RMS) of 0.77 K) is obtained for a thermal diffusivity of $0.4\cdot 10^{-6} m^2 s^{-1}$, indicating that heat conduction is the dominant heat-transfer mechanism, especially in the time interval April 27th 2003 – June 26th 2003. In summer and autumn however, measured temperatures at 1 m are systematically lower than the predicted ones, probably because of evapotranspirative cooling. Taking into account non-conductive processes such as water movement, the calculation of an apparent thermal diffusivity would probably illustrate better what can already be seen from Fig. 7, that is the seasonal variation of the thermal properties of the soil.

## AIR-SOIL TEMPERATURE COUPLING

It is generally accepted that ground surface temperatures are higher than air temperatures (Beltrami and Kellman, 2003), and the Romanian stations make no exception. In Fig. 8 the comparison between the two temperatures is presented. One can notice that the soil temperatures track the air temperatures. The range of the RMS difference between soil and air temperatures ranges between ± 1.70 (Oradea) and ± 3.08 K (Reşiţa). For the ten stations the mean RMS difference is ± 2.26 K. The mean difference between surface and air temperatures for individual stations ranges between 0.52 K and 1.66 K; the overall mean difference for the 10 stations of the study is 1.07 K.

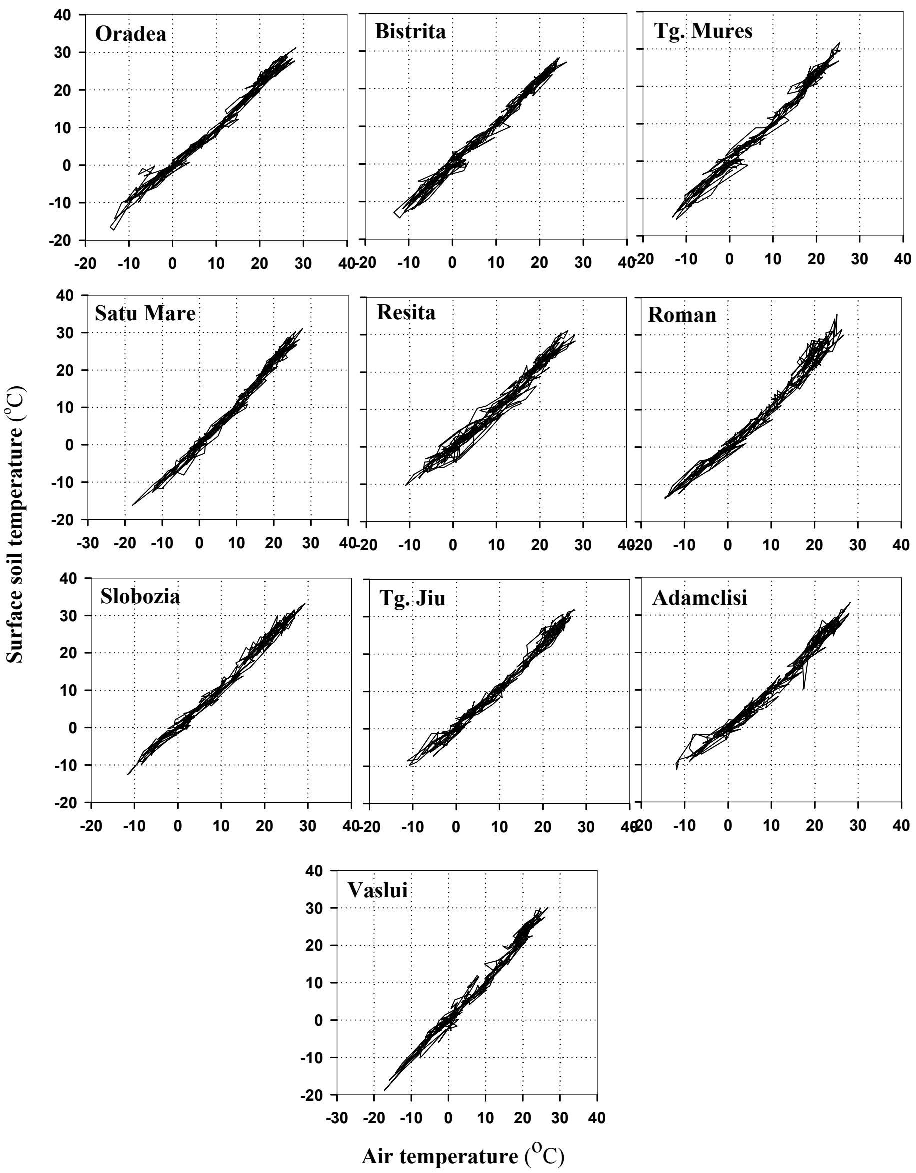


Fig. 8 – Comparison of air and soil surface temperatures measured at ten automatic stations from Romania for 2003.

## CONCLUSIONS

The preliminary analysis of air and soil temperature data acquired by the new automatic Romanian weather network, reported here, shows that:

– the soil surface temperature tracks the air (2 m) temperature within ± 2.26 K for all 10 stations; the range of the RMS difference ranges between ± 1.70 K (Oradea) and ± 3.08 K (Reşiţa). The mean difference between surface and air temperatures for individual stations ranges between 0.52 K and 1.66 K; the overall mean difference for the 10 stations of the study is 1.07 K;

– the effective thermal diffusivity for the first meter of ground shows seasonal variations;

– simple conductive models cannot reproduce recorded soil temperatures during the freezing season or during the summer. Incorporating latent heat contribution to the heat transfer in the active layer is a necessary step;

– detailed studies on heat transfer through the upper meter of the ground would be possible upon changes in data acquisition protocol (sampling rate down to 0.5 minutes).

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