Physiographical Study On the Extent of Effects Contributed by Soil Temperature and Humidity On Ground Heat Flux Rates

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Abstract. The ultimate objective of this research was to first assess the contribution of soil temperature and soil moisture on Ground Heat Flux (GHF). The specific objective was to determine GHF. To address these objectives, a field experiment was conducted in a vineyard located in Quebec, Canada during the spring of 2015. The results show that the change in soil temperature is of greater importance than soil humidity in the GHF variation range.

1. Introduction

Soil constitutes a major storage location for heat, and acts as a sink for energy during the day and a source of heat for the Earth’s surface at night. Surface ground heat flux, or the exchange of heat energy between the soil surface and subsoil generated by the combined actions of multiple factors, is a key component of the energy balance of the Earth's surface. Indeed, ground heat flux is acknowledged as an important component of the surface energy balance in stable nocturnal conditions (e.g. radiation frost) particularly in agricultural terrain [1, 2].

Investigations on the influence of soil moisture and temperature on measured ground heat flux first began in the 1950’s, when resistance thermometers had led to a multitude of soil temperature surveys [3]. Together with the fundamental works of De Vries on thermal conductivity and of Geiger [4] on near ground climatology, the scientific basis for the understanding of the processes and influencing variables of heat exchange and storage in the soil-vegetation-atmosphere continuum was provided.

In recent years, there is a steady trend of growing consideration for ground heat flux. Indeed, micrometeorological research has shifted towards areas where the ground heat flux is a more important component of the surface energy budget [5, 6].

In the following years, different methods that have enabled the numerical quantification of surface energy and matter fluxes at the local scale have been proposed or compiled [7]. Recent studies have found that the correct determination of heat storage within the soil-vegetation-atmosphere system is a key factor in the solution of the surface energy imbalance [8, 9]. As a component of the surface energy balance, the ground heat flux plays an important role in the surface energy budget; its accurate
estimation can improve the surface energy budget closure significantly, especially over surfaces with bare soil or sparse vegetation [5]. On the other hand, in many micrometeorological problems (one example being evaporation) it is necessary to evaluate as precisely as possible the variation terms in the soil heat flux mechanism. While many models employ surface soil temperature to predict the ground heat flux, in general, the treatment of soil moisture remains very crude.

In fact, additional work is needed to investigate and refine the relationship between ground heat flux and soil temperature and humidity. Consequently, the main objective of this research was to assess the contribution of soil temperature and soil moisture on soil heat flux. To achieve this end, the specific objective was to determine soil heat flux using a temperature gradient method.

2. Methodology
The methodology was based on three essential components: 1) field measurement, 2) estimation of ground heat flux, and 3) physiographical analyses.

2.1 Field measurement
This study was carried out in Domaine Bergville, a commercial vineyard located in Quebec (Canada) during the spring of 2015. Two stations were installed at two different sites. One of the stations was installed in a clear-cut area (termed the “Upper Station” at an altitude of 262 m) and the second station was placed at a distance of 110 m from the center of the clear-cut area; this second station was situated in a shelter-wood region (called the “Lower Station” at an altitude of 250 m), and was shielded by a forest arc formation. The in-situ measurements used in this study included soil temperature (at the ground surface and at a depth of 30 cm), soil moisture or soil water content (at the ground surface and at a depth of 30 cm), and air temperature (at 1.70 cm above the ground surface). Measurements were performed at 5 minute intervals.

2.2 Estimation of ground heat flux
Using equation (1) the ground heat flux for both the Upper and the Lower Station were calculated [7]:

\[
Q_g = k \frac{dT}{dz} + \rho C \frac{dT}{dt}
\]  

(1)

Where \( Q_g \) is the ground heat flux (w/m²), \( k \) is the thermal conductivity, and \((dT/dz)\) is the vertical soil temperature gradient. In this research, the gradient is between the soil surface and soil temperature at 30 cm depth. \( \rho \) is soil density, \( C \) is soil specific heat, and \((dT/dt)\) is the temporal temperature gradient of 25 days for this study. Soil specific heat was calculated using equation (2), as follows:

\[
C = B_D(C_s + wC_s)
\]  

(2)

Where \( B_D \) is the soil bulk density, \( C_s \) is the dry soil specific heat capacity, and \( w \) is the soil water content [7].

2.3 Physiographic analyses
In this section, physiographical analyses based on the observed measurements and estimated values are presented. In addition, the weight percentage diagrams of the soil parameters against heat flux were derived. It should be noted that a variety of parameters such as long wave radiation, upward conduction and convection of heat into the atmosphere may bring about subsequent energy transformations. These kinds of parameter are thus referred to as the “other parameters” for the remaining sections of this paper.

3. Results and Discussions
The data were analysed to show the importance of horizontal variation in surface moisture and surface temperature and their impacts on ground heat flux. Figures 1 and 2 show the time series variation of soil, moisture and heat flux over the experimental period for the two stations (i.e. the Upper Station and Lower Station). As the figures indicate, the temporal variation pattern of ground heat was very
similar to the soil temperature variation rather than with the moisture. The temporal variation on the ground flux did not follow the pattern of moisture. However, as the figures illustrate, the ground heat flux is enhanced when the soil possessed greater humidity, which decreases the intensity of the net radiation and available energy response.

**Figure 1.** Time series variation of soil temperature, soil moisture and ground heat flux for the Upper Station

**Figure 2.** Time series variation of soil temperature, soil moisture and ground heat flux for the Lower Station

A comparison between the two stations (spatial view aspect) shows the amplitude variation of the ground heat flux over the Lower Station was higher than that of the Upper Station. In a microclimatological aspect, the Lower Station was surrounded by forest and was also 12 metres lower than the Upper Station, where cold air stagnated. Conversely, the Upper Station was situated in an open area where stagnation of cold air did not occur. In addition to soil properties, certain atmospheric effects also play an important role in ground heat flux variation. It should be noted that the observations clearly show that the ground heat flux as a function of time is more variable than the soil temperature.

In order to more carefully determine the contribution of soil temperature and humidity as well as the other microclimate parameters, two thematic diagrams were derived (Figures 3 and 4). The figures show the importance of the contribution of soil moisture, soil temperature, and other parameters (such as micrometeorological effects) in percentage (%) format. As the figures present for both stations, soil temperature is the most important factor, and the role of micrometeorological aspects depend strongly on the soil humidity. In fact, soil moisture is able to decrease the contributions of micrometeorological aspects in ground heat flux values. Comparisons between the two stations show that the percentage of
soil moisture of the Upper Station (open area) in the ground heat flux value is higher than the percentage of soil moisture of the Lower Station (shelter-wood area). This may be due to greater evaporation in open areas compared to sheltered areas. Therefore, within the shelter-wood zone or shadowed areas, soil moisture was less important than for the open areas in the field of ground heat flux and thus for the available energy. Conversely, for an open area, the soil humidity was more highlighted.

Figure 3. Soil moisture, soil temperature and the other parameters percentages in the ground heat flux values over the Upper Station (open area example).

Figure 4. Soil moisture, soil temperature and the other parameters percentages in the ground heat flux values over the Lower Station (shelter-wood area example).

In order to further this discussion, the gradient of ground heat flux, soil moisture and soil temperature between the two stations were calculated; these results are presented in Figure 5. The greater difference between the heat flux values of the two stations were observed when there was a higher soil temperature gradient. As Figure 5 indicates, there is no clear pattern for soil moisture. However, over this period, the highest gradient of ground heat flux was associated with a higher moisture gradient.
4. Conclusions
The result clearly illustrates the importance of soil temperature contribution in comparison to soil humidity in the ground heat flux. The measurement of ground heat flux can be a difficult task yet; however, based on the results shown in this research (namely that soil temperature is the most significant factor in these types of analyses), the utilization of a simpler model based solely on soil temperature is recommended. Additionally, the soil humidity caused by the evaporation process within an open area may play a more important role in the available energy partition in comparison with shadow or shelter-wood areas.

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