P 2.7 THE SURFACE ENERGY BALANCE OVER A DESERT, AND THE RELEVANCE OF SOIL HEAT FLUX MEASUREMENTS

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1. INTRODUCTION

This study analyses observations of the separate components of the surface energy balance, with emphasis on the Soil Heat Flux (SHF), in the Negev desert in Israel.

Traditionally, the SFH measurements are performed using a thermopile sensor, with a known thermal heat conduction coefficient, diameter and thickness (Philip, 1961). These SHF plates are usually buried at a certain depth, to avoid interference with biological activity at the surface. These measurements then represent the heat flux at that depth. Corrections are needed to calculate a SHF at the surface.

In this study, the SHF measurements are obtained using a new approach, whereby the SHF is measured directly at the soil surface. This new method is compared with traditional SHF measurements for validation. An accurate validation is possible, thanks to the soil being very homogeneous and the lack of vegetation cover.

The very low vegetation density and the dryness of the desert, made it relatively simple to test the individual components of the surface energy balance. If the separate components of this balance are measured correctly, their sum should be zero. This check is called the SEBCT (Surface Energy Balance Closure Test). Since the SHF can be as high as the sensible heat flux, it is a very important factor in the SEBCT.

2. THEORY

The surface heat flux conducts downward into the soil. This process depends on the soil thermal characteristics. The SHF will be highest at the surface, and will vanish quickly with increasing depth, as does the temperature wave. The thermal properties of the soil are a function of soil type, soil structure, soil moisture, depth, etc. To measure a SHF with a buried SHF sensor and convert this to a surface SHF requires additional measurements of temperature and soil thermal properties (as a function of depth).

With this conventional set-up, there are 2 major ways to find the SHF at the surface: The calorimetric method and the fourier analysis of the temperature profile. The first method requires additional measurements of soil heat capacity and soil heat conduction, so the second method is preferred because these parameters can also be solved with this method, provided that the soil is homogeneous.

The surface SHF measurements were validated with the harmonic wave analysis on the measured temperature profile and on measured SHF from SHF sensors at two depths. The background for this method is the soil temperature diffusion equation. The soil temperature profile in a homogeneous soil (Van Wijk, 1963) is:

$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial z^2}. \qquad (1)$$

Here $\kappa = \lambda / C$, the thermal diffusivity , λ is the heat conduction coefficient and C is the volumetric heat capacity. With the aid of a fast fourier expansion, an analytical solution T(z,t) of equation one, can be found. The derivative of this solution multiplied with the soil thermal conductivity, gives the soil heat flux as a function of depth and time (equation 2).

$$G_{z,t} = -\lambda \frac{\partial T_{z,t}}{\partial z}. \qquad (2)$$

The unknown soil thermal properties are found by fitting equation 1 and 2 to the real data. This is an elegant technique to determine soil thermal properties also. Equation 1 is a perfect test for soil homogeneity, provided that there are accurate soil temperature profile measurements available.

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The measurements of the separate components of the energy balance are complex. It is therefore important to have a possibility to check these measurements. A very common technique to do this is the SEBCT (Surface Energy Balance Closure Test). This is usually presented in its basic form:

$$R_n = H + L_v E + G + X \,. \quad (3)$$

Where, R_n is the net radiation, H is the sensible heat flux, $L_v E$ is the evaporation, G is the soil heat flux and X represents additional terms. Often X is neglected. Then, equation 3 assumes an ideal case, where all the components are measured at the interface between surface and atmosphere or corrected as such. Since fluxes are normally measured at a certain distance away from the surface, X represents:

$$X_{n,h} = Y + A + h_r \frac{\partial R_n}{\partial z} + \frac{\partial S_b}{\partial t} \,. \quad (4)$$

$$Y = C_s \int_{z_{HFS}}^{0} \frac{\partial T}{\partial t} \partial z + C_a \int_{0}^{h} \frac{\partial T}{\partial t} \partial z + L_v \int_{0}^{h} \frac{\partial q}{\partial t} \partial z$$

Where Y represents a heat storage component change over the evaluated time interval, the first term is the heat storage above the SHF sensor, the second term is the heat storage change in the air between the sensor and the soil, the last term is the change of moisture. A in equation 4 is an advection term and the last two are respectively the radiation divergence and a change in (chemical) energy storage in biomass.

3. MATERIALS AND METHODS

Experiments were taken place in the year 2000 in the Negev desert, in a longitudinal sand dune system in the west of Israel (30.90° N, 34.4° E and +210 m above m.s.l.), at the end of the dry summer season. The flux station was located in a flat region between two longitudinal dune systems. The prevailing wind direction is through the valley. The valley soil has a thick compacted layer of silt and clay. The soil light extinction coefficient is very high, thus it is possible to install an SHF sensor very close to the surface and cover it with a thin layer of sand. This thin layer is needed, so that the SHF sensor has the same albedo as the surrounding soil.

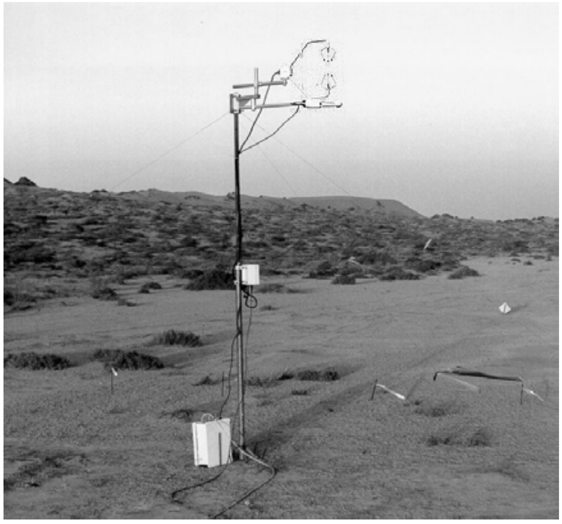

Figure 1. Eddy covariance flux station, at 3 m height

A tower (height 3 m) was instrumented with an eddy-covariance system consisting of a 3D sonic anemometer (Campbell CSAT3) and an infrared CO_2/H_2O gas analyzer (Li-Cor Li-7500), see figure 1. The measurements were recorded on a continuous basis at a 0.1 second time interval. These raw samples were processed using our eddy covariance processing software package. This processing includes all necessary corrections like axis rotation, density corrections, etc.

In its vicinity, a mast (height 1 m) instrumented with short-wave and long-wave radiometers (Kipp, CM14 and CG2) measured the radiation balance. SFH (TNO) and temperature sensors were installed nearby. Two SFH sensors were installed very near to the surface. They were covered with a very thin layer of sand. The SFH sensors were factory calibrated, and their heat conductivity was $0.25 Wm^{-1}K^{-1}$,a value close to that of the desert soil at the experimental site. So, shape corrections as proposed by Mogensen, (1970), are not needed.

The experimental campaign started in September 2000, and lasted for about 5 weeks. This generally is a very dry period, so soil moisture content is very low.

4. MEASUREMENTS AND ANALYSIS

The majority of the analyzed days were very dry. However, almost every day there was some dew formation (Jacobs, et al, 1999). Therefore, the condensation and evaporation were measured also.

4.1 Soil heat flux

The SHF as measured at two depths is presented in figure 2. It shows that the remaining SHF at 0.046m, is only a fraction of what it is at the surface. Also, it shows that it is time shifted. It is obvious that it is difficult to recover the surface SHF from the buried sensor. Secondly, it shows the very dynamic behavior of the surface SHF.

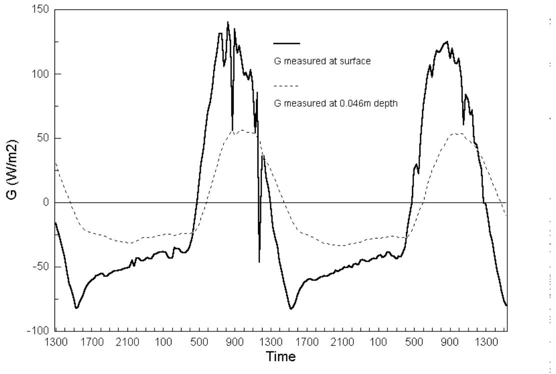

Figure 2. Daily courses of soil heat fluxes measured at two depths (2 day period)

The soil heat flux calculated from the soil temperature profile together with the buried soil heat flux sensor, using the harmonic analysis, gives a similar result as measured from the SHF sensor at the surface. However, it is important to take into account very high order harmonics in the fourier analysis. From this analysis the soil damping depth appeared to be 0.065m. This low damping depth is also responsible for the fast reaction of the soil heat flux to the radiation. The sharp peaks in the first day with scattered clouds are in fact correct measurements. Within 15 minutes, the SHF can change by more than 100 W/m^2.

4.2 Surface energy balance

As an example, two days of surface energy balance fluxes have been plotted in figure 3. These fluxes are already corrected for their measurement height. These two days were selected to show how it works on two different days. On the fist day, there was some evaporation of a few raindrops (about 0.2mm) of the previous night, followed by dew (also 0.2mm), there was no cloud cover. The second day had clouds (no rain). For the SHF measurements no correction was needed, since the surface SHF sensor was used only. This simplified the analysis, so only the air temperature change of the heat storage terms in *Y* (equation 4) was important. Especially in the morning hours $\partial T / \partial t$ is large, this contributed to up to 8 W/m^2. Although not measured directly, large advection terms are not to be expected. This is based on the fact that the terrain is very homogeneous.

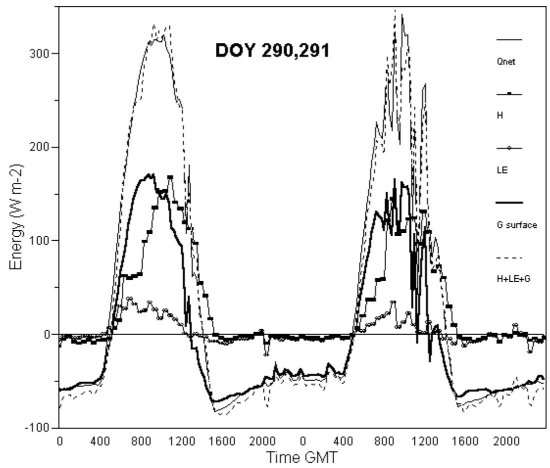

Figure 3. The daily course of the energy fluxes at the surface

Figure 4 shows a scatter diagram of measured fluxes, they already include all corrections (right hand side of equation 4), versus the Net radiation.

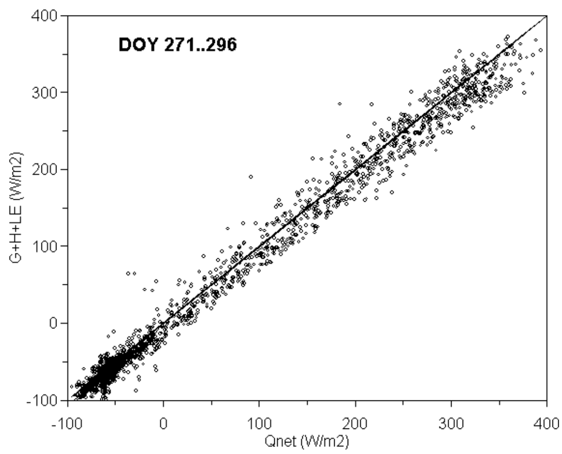

Figure 4. Scatter diagram between the eddy-correlation measurements including corrections according to equation four, compared with the net radiation (year 2000). There was no data omitted.

From the scatter diagram of figure 6 we can infer that the closure is very good (slope 1.0, R^2=0.99).

5. CONCLUSIONS

The new surface Soil Heat Flux (SHF) measurements accurately measure the soil heat flux at the surface. This is validated, by comparing these measurements with traditional SHF measurements including its corrections. The fourier analysis is a very powerful tool to do this, provided that there are accurate temperature profile measurements available.

The surface energy balance closure test shows that the sensible heat flux as measured with the Eddy Covariance system, is reliable for the cases examined here.

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