STUDY OF THE RELATIONSHIP BETWEEN SURFACE NET RADIATION AND SOIL HEAT FLUX BY USING VALENCIA ANCHOR STATION GROUND MEASUREMENTS AND GERB/SEVIRI DATA

Antonio Geraldo Ferreira \textsuperscript{1,2}, Almudena Velázquez Blázquez\textsuperscript{1}, Emilio Soria\textsuperscript{3}, Ernesto Lopez-Baeza\textsuperscript{1}, Javier Sanchis Muñoz\textsuperscript{1}

\textsuperscript{1}University of Valencia – Faculty of Physics - Department of Physics of the Earth and Thermodynamics.
\textsuperscript{2}University of Valencia – ETSE - Department of Electronic Engineering
Calle Dr Moliner 50 - 46100 Burjassot – Valencia-Spain
\textsuperscript{3}Fundação Cearense de Meteorologia e Recursos Hídricos-FUNCEME - Av. Rui Barbosa, 1246 - CEP 60115-221 -Fortaleza – CE- Brazil -email:antonio.ferreira@uv.es

Abstract

Remote sensing techniques can be used to retrieve surface parameters and properties at regional scales. One of these parameters is soil heat flux, \(\mathbf{G}\), a significant term of the surface energy balance equation, \(\mathbf{Rn} = \mathbf{H} + \mathbf{LE} + \mathbf{G}\), mainly in semi or arid regions. In that equation, \(\mathbf{Rn}\) represents net radiation, \(\mathbf{H}\) the sensible heat flux and \(\mathbf{LE}\), the latent heat flux. In this work, the relationship between \(\mathbf{Rn}\) and \(\mathbf{G}\) is studied over vineyard crops, by using micrometeorological observations and METEOSAT Second Generation (MSG) images. Originally, we used micrometeorological data from the EFEDA (ECHIVAL Field Experiment in a Desertification Threatened Area, Castilla-La Mancha, Spain) experiment, for which we obtained linear models to derive \(\mathbf{G}\) directly from \(\mathbf{Rn}\) with a Pearson correlation coefficient \((\mathbf{r})\) between 0.829 and 0.973 and a root mean square error \((\text{rmse})\) varying between 16 Wm\(^{-2}\) to 37 Wm\(^{-2}\), depending on the site measurements. These linear models have been the driving mechanism to apply and extend the analysis to longer time series of \textit{in situ} data during the field campaigns carried out between 2004 and 2007 at the Valencia Anchor Station (VAS) in the framework of the SCALES (SEVIRI/GERB Cal/val Area for Large scale field ExperimentS) Project. We try now to extend and extrapolate these \(\mathbf{G}\) estimations to larger areas, at satellite observation scales, to provide reliable estimations of \(\mathbf{G}\), directly derived from net radiation measurements, at adequate regional scales. This extension of the methodology to remote sensing data is being carried out through the application of the synergy between \textit{GERB} (Geostationary Earth Radiation Budget) and \textit{SEVIRI} (Spinning Enhanced Visible and Infrared Imager) data to provide estimates of net radiation and surface temperature with unprecedented frequency of 15 min intervals.

1. INTRODUCTION

The energy exchange between the land surface and the atmosphere can be described by the surface energy balance equation given by:

\[\mathbf{Rn} = \mathbf{H} + \mathbf{LE} + \mathbf{G}\]  

where \(\mathbf{Rn}\), represents net radiation, \(\mathbf{H}\), the sensible heat flux, \(\mathbf{LE}\), the latent heat flux and \(\mathbf{G}\), is the soil heat flux at surface.

In this equation \(\mathbf{G}\) is typically the smallest term and it is often estimated as a constant function of \(\mathbf{Rn}\), as a residual term of the Eq. (1), or assumed to be negligible on daily time scales (Santanello and Friedl, 2002). However, studies carried out by Kustas \textit{et al.} (1993), based on field measurements, showed that \(\mathbf{G}/\mathbf{Rn}\) can vary between 0.05 and 0.50, depending on the period of the day, thermal properties of the soil, soil moisture and land cover, i.e., vegetation characteristics (amount and height). According to Murray and Verhoef (2007), for relatively sparse vegetation, \(\mathbf{G}\) can consume a significant proportion of \(\mathbf{Rn}\), moreover, during the night \(\mathbf{G}\) is an important term in the energy balance, when low
values of $R_n$ and stable atmospheric conditions cause $H$ and $LE$ to be small. Nevertheless, in situ values of $G$ or determined by existing methods are valid for an area of much less than 1 $m^2$ (Verhoef, 2004). In addition, for surface energy balance studies, accurate determination of $R_n$ is very important, because its magnitude is directly related to the rest of heat fluxes, as it can be seen in Eq. (1). But, despite its importance, $R_n$ is not measured frequently and a few historic data area available in the majority of standard meteorological stations (Sentelhas and Gillespie, 2007).

Taking these issues into account, the objective of this study is to evaluate the relationship between $R_n$ and $G$ over a vines crop at a local scale, by using in situ micrometeorological parameters and satellite data to estimate the entire diurnal cycle of $G/R_n$, based on satellite Land Surface Temperature ($LST$) assuming that $LST$ is equal soil temperature at surface. The extension of the methodology to wider areas is being done by means of simulated GERB $R_n$ at surface level.

2. DATA AND METHODOLOGY

2.1 Data

In this work, the relationship between $R_n$ and $G$ is studied over vineyard crops, by using: a) micrometeorological data, averaged over a half hour period, from the EFEDA experiment, which was carried out in June, 1991 at Castilla-La Mancha, Spain (for more details see Braud et al, 1993 y Bolle and Streckenbach, 1993), b) micrometeorological data, averaged over a ten-minutes period, from FESEBAV-2006 and 2007 (Field Experiment on Surface Energy Balance Aspects in Valencia anchor station area) carried out between 31th July – 5th September 2006 and 28th May - 18th September 2007, respectively, and c) METEOSAT Second Generation (MSG) images with a frequency of fifteen minutes.

In situ data (surface temperature, net radiation, soil heat flux, water vapour, ozone and aerosols profiles) collected during the field campaigns carried out between 2004 and 2007 at the VAS in the framework of the SCALES Project have also been used in this study. The VAS (latitude 39º 34’ 15”N and longitude 1º 17’ 18”W) is located on the plateau of Utiel-Requena, 80 km from Province of Valencia-Spain, and represents a homogeneous area of 50 km x 50 km dedicated primarily to growing vines.

The MSG satellite images corresponding to $LST$ retrieved with SEVIRI, and Top of the Atmosphere shortwave and longwave fluxes measured by GERB, for the field campaign period, were obtained from the Land Surface Analysis Satellite Applications Facility (LandSAF) - Landsafl.meteo.pt and from the Royal Meteorological Institute (RMIB) On Line Short-term Service ftp, respectively.

2.2 Methodology

The main objective of this work is to make a study of the relationship between $R_n$ and $G$ over a vineyard crop using in situ micrometeorological and soil data measurements as well satellite data as described bellow.

2.2.1 Soil heat flux at surface ($G$) estimation

The soil heat flux at surface, for both, EFEDA and FESEBAV-2006/2007 experiments, was estimated following the methodology proposed by (Braud et al, 1993):

$$G = G_{(z=7.5cm)} + C_v \Delta z \left( T_s^{l_1} (1cm) - T_s^{l_0} (1cm) + \frac{\Delta T_s^{l_1} - \Delta T_s^{l_0}}{2} \right) / Dt$$

where $G_{(z=7.5cm)}$ is the soil heat flux ($Wm^{-2}$) at 7.5 cm depth in the soil, $T_s$ is the surface temperature, $\Delta T_s$ is the temperature gradient between the surface $z_0$ and $z_2 = 7.5$ cm, $t_0$ and $t_1$ are two consecutive time steps, $\Delta z = 7.5$ cm, $Dt = 30$ min, and the $C_v$ is volumetric soil heat capacity ($J/m^3 ^\circ C$) that was calculated according De Vries (1963):
\[ C_v = 4.18 \times 10^6 (0.46 \theta_m + 0.60 \theta_o + \theta_w) \]  

(3)

where \( \theta_m \) = fraction of mineral matter, \( \theta_o \) = fraction of organic matter, \( \theta_w \) = fraction of water. \( \theta_m \) and \( \theta_o \) were calculated in laboratory and \( \theta_w \) was measured continually, \textit{in situ}, as well as \( T_s \) and \( G(z=7.5\text{cm}) \) by using a ThetaProbe soil moisture sensor, Platinum resistance thermometers PT100 and Rimco HP3 Heat Flux Plate respectively.

2.2.2 Linear regression models

After calculating \( G \), by using Eq. (2), the next step was to make scatter plots between \( G \) and \( Rn \), where \( Rn \) was measured in the micrometeorological stations installed in the sites in study. Once it was found that there was an increasing linear trend between \( Rn \) and \( G \) we fitted a simple linear regression model to correlate them. The results are presented in Table 1 and Figures 2(a), (d), (g) and (j).

2.2.3 Simulated GERB shortwave and longwave fluxes at the surface

In order to develop a suitable methodology able to obtain \( G \) over wider areas and due to the lack of retrieved net radiation from GERB at the surface, we have simulated GERB shortwave and longwave fluxes at the surface, hereafter called GERB \( Rn \), over the study area. The radiative transfer simulations of fluxes were made using independent ground measurements of surface and atmospheric parameters gathered during the field campaigns (Velázquez, et al., 2006 and 2007), such as:

- Water Vapour: Radiosounding ascents interpolated to 1m resolution and completed with MLW and MLS (Mid Latitude Winter or Summer) profiles. Up to 94-95 levels are selected and the profile is scaled to the integrated water vapor retrieval obtained with the GPS (Global Positioning System) (Figure 1 (a) and (b)),
- Ozone: MLW profile scaled to TOMS (Total Ozone Mapping Spectrometer) values,
- Aerosols: STREAMER MLW standard profile, assuming background tropospheric aerosols and background stratospheric aerosols and aerosol optical thickness from CIMEL photometer measurements,

Figure 1: (a) and (b): Precipitable water content measurements from the GPS receiver (blue dots) and radiosounding ascents (red circles)
2.2.4 The quotient $G/Rn$

Before calculating the relationship $G/Rn$ using Eq. (3), that requires surface temperature information, a comparison between $T_s$ and LST was made for a specific day 1st August 2006. Once observed that the surface temperature measurements, made in situ and estimated by the sensor SEVIRI, presenting small deviations between them, the next step was calculating the relationship $G/Rn$, using LST retrieved with MSG/SEVIRI, for the day mentioned before. It was performed applying the methodology proposed by Santanello and Friedl (2002),

$$
\frac{G}{Rn} = (0.0074\Delta T + 0.088) \cos \left( \frac{2\pi (t + 10800)}{B} \right)
$$

where $T$ is the temperature (K) and $t$ is the time (s). $B = 1729(\Delta T) + 650113$ and should ideally be assigned based on knowledge of soil type, moisture regimes, and the seasonal dynamics in Leaf Area Index ($LAI$). After calculating the quotient $G/Rn$, it was possible derive $G$ using GERB $Rn$ that was calculated as described in item 2.2.3. The results can be seen in the Figure 4.

3. RESULTS AND DISCUSSION

The scatter plot of $Rn$ observed, versus $G$ estimated, following Eq. (2) and the corresponding one to $G$ observed versus $G$, estimated using linear models (Table 1), for a specific day, are presented in the figure 2. The figures 2(a), (d), (g) and (j) show a straight line through the "cloud" of data points for the in situ data collected during EFEDA (by CNRM and COP groups), FESEBAV-2006 and FESEBAV-2007 experiments respectively. The linear models fitted for each studied site, with the error of fit for each equation are summarized in Table 1. For the vine sites studied, the results showed that, in average, $G$ component was approximately 26% of $Rn$. 

![Figure 2](image_url)

*Figure 2: (a, d, g and j): scatter plot of Rn (observed) versus G (estimated – Eq. (2)) with straight line through the “cloud” of data points and (b, c, e, f, h, i, k and l): plot of G (Eq. (2)) versus G (linear model fitted) for a specific day.*
Table 1. Linear models obtained for each studied site. Also included are the values of Pearson correlation coefficient (r), Standard Deviation (std) and the Root Mean Square Error (RMSE) of the comparisons. CNRM stands for Centre National de Recherches Meteorologiques (CNRM) and COP stands for University of Copenhagen (COP).

<table>
<thead>
<tr>
<th>Site</th>
<th>Crop</th>
<th>Linear Model</th>
<th>r</th>
<th>std</th>
<th>RMSE (Wm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNRM (Tomelloso)</td>
<td>Vineyard</td>
<td>G = 0.2544Rn – 22.20</td>
<td>0.829</td>
<td>71.9</td>
<td>37</td>
</tr>
<tr>
<td>COP (Tomelloso)</td>
<td>Vineyard</td>
<td>G = 0.3124Rn – 24.39</td>
<td>0.973</td>
<td>70.3</td>
<td>16</td>
</tr>
<tr>
<td>FESEBAV-2006</td>
<td>Vineyard</td>
<td>G = 0.1976Rn – 23.68</td>
<td>0.874</td>
<td>51.7</td>
<td>25</td>
</tr>
<tr>
<td>FESEBAV-2007</td>
<td>Vineyard</td>
<td>G = 0.2867Rn – 38.60</td>
<td>0.914</td>
<td>70.8</td>
<td>20</td>
</tr>
</tbody>
</table>

In order to make possible the comparison between simulated GERB Rn at the surface and the measured in the field campaigns, the comparisons have been done at a spatial resolution of 1km, over the VAS and over the vineyard mobile micrometeorological station, showing good agreement for both periods and stations, winter of 2004 at VAS, and summer of 2006 over vineyards. RMSE of 17 Wm$^{-2}$ and 42 Wm$^{-2}$, respectively, high Pearson correlation, and low standard deviations indicate that the methodology applied is able to reproduce net radiation at surface level (Table 2).

Figure 2: Continuity

Figure 3: Net radiation comparisons between simulated Rn and measured Rn at (a) VAS and (b) vineyards.
3.1 Land surface Temperature from SEVIRI and micrometeorological station

The linear models presented above are valid for the specific site where the data were collected, but normally we are interested in estimate $G$ and $Rn$ not only on a local scale, but also at regional scales. To reach this objective we need to use an alternative methodology for the estimation of $G$ and $Rn$, for example, a methodology that make possible use satellite data. This methodology (Eq. (3)) was proposed by Santanello and Friedel (2002), where the surface temperature can be obtained from SEVIRI that provide estimates of LST with unprecedented frequency of 15 min intervals with a spatial resolution of 3.1 km, covering totally the diurnal course of the LST.

In order to test this methodology a study case based on surface temperature measured during the FESEBAV-2006 and retrieved by MSG/SEVIRI, for the day 06/01/2006 was made. The relationship between measured and estimated LST every 15 minutes is presented in Figure 4. The correlation between the ground measurements and SEVIRI LST was quite good, presenting a Pearson correlation coefficient $r$ of 0.96, with a square of the correlation coefficient $R^2$ of 0.93 and RMSE of 3.51 °C, and std of 3.52 for SEVIRI LST.

![Figure 4](image)

Figure 4: (a) SEVIRI and micrometeorological station LST comparison for August 01, 2006, (b) simulated $G/Rn$ using LST from SEVIRI, (c) retrieved $G$ from GERB $Rn$ simulated.

The $G/Rn$ estimation over a vineyard crop by using Eq. (3) showed that it can range from -0.30 to 0.37 depending on the time of the day, reaching maximum values in mid-morning, and a minimum values at about mid-night (Figure 4 (b)). Once we have obtained the ratio between $G$ and $Rn$, it is possible to estimate the diurnal course of $G$ by using the results of the simulation of GERB $Rn$ (Figure 4(c)). In the Figure 4(c), it can be seen that the maximum value of $G$ is reached at about three hours before $Rn$ reaches its maximum value. According to Anandakumar et al. (2001), it can be explained by the fact that the soil surface is heated up in the morning hours, as a consequence the temperature difference between the surface and air increases, and a significant amount of heat is transferred to the overlying atmosphere in the form of $H$ and $LE$.

4. CONCLUSIONS

The results indicate that there is a good linear correlation between $Rn$ and $G$: 82.9%, 97.3%, 87.4% and 91.4% (see Table 1), during vine growing season. The remaining 17.1%, 2.7%, 12.6% and 8.6%, respectively, can be explained such as variations caused by other factors not considered in the regression model like $H$ and $LE$. 

<table>
<thead>
<tr>
<th></th>
<th>12th February 04</th>
<th>1st August 06</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>17</td>
<td>42</td>
</tr>
<tr>
<td>$r$ Pearson</td>
<td>0.994</td>
<td>0.990</td>
</tr>
<tr>
<td>std</td>
<td>17.3</td>
<td>35.5</td>
</tr>
</tbody>
</table>

Table 2: RMSE of the comparison, $r$ Pearson and standard deviation of the $Rn$ simulated.
The comparisons between simulated and measured $Rn$ shown good agreement in both periods, winter (2004) and summer (2006), showing low $RMSE = 17 \text{ Wm}^{-2}$ and 42 $\text{Wm}^{-2}$, respectively, indicating that the methodology applied is able to reproduce net radiation at surface level under clear sky conditions.

For the studied case (August 1, 2006), although the spatial scale of SEVIRI and the corresponding one to the ground measurements is significant, we find that for the comparison, over a vineyard, a low $RMSE$ of 3.5 °C.

The methodology here shown has allowed us to retrieve $G$ from the empirical ratio of $G/Rn$ and simulated Surface Net Radiation. From this preliminary study it is possible to visualize the importance of using the synergy between GERB and SEVIRI in order to derive $Rn$, and consequently $G$ over local and regional areas. Further studies will include the calculation of $Rn$, and consequently $G$ at GERB pixel spatial resolution.

5. REFERENCES


Santanello, J. A., Friedl, M. A. 2002. Diurnal relationships between soil heat flux and net radiation over a range of surface conditions applied to land surface energy balance modeling. JP1.5 - Land Atmosphere Interactions (Joint with the 16th Conference on Hydrology and the 13th Symposium on Global Change and Climate Variations), Orlando, FL-USA.


ACKNOWLEDGEMENTS

This work was supported by the Programme Alβan, the European Union Programme of High Level Scholarships for Latin America, scholarship no. E05D058998BR – Antonio Geraldo Ferreira. The authors gratefully acknowledge the assistance of Calibration of SMOS MIRAS Radiometer Measurements and Generation of Maps of Salinity and of Soil Moisture Content, UVEG Part (MIDAS-4/UVEG), Spanish Ministry for Education and Science (National Research Programme on Space), Remote Sensing Techniques for the Observation of Environmental Parameters in the Valencia Community Autonomous Region. Contract Department for Environment, Water, Planning and Housing, General Directorate for Environmental Quality /Climate Change, Generalitat Valenciana, GERB International Science Team (GIST), CERES Science Team, La Cubera, El Renegado and Canyada Honda Vineyard Fields and Wine Cellars, Valencia, Spain, Land Analysis SAF and EUMETSAT.