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Evapotranspiration Estimate Using Energy Balance Two Source Model With UAV Images: A Study in Vineyard

Maurício Soares Ortiz[1,2], Jorge Ricardo Ducati[1], Jean Espinoza[2]andRodrigo Câmara Monteiro[2]
[1](Federal Universityof Rio Grande do Sul – UFRGS, Porto Alegre – RS, Brazil)
[2](Federal Instituteof Science and Technologyof Rio Grande do Sul – IFRS, RS, Brazil)
Corresponding Author: MaurícioSoares Ortiz

ABSTRACT :*The present work proposed the application of geoprocessing methodologies for the determination of the water balance of the vineyard region in the Serra Gaúcha(Pinto Bandeira, RS, Brazil), with a UAV (Unmanned Aerial Vehicles) flight at the Winery. The instrument for the determination of the factors involved in the estimation of evapotranspiration were acquired through remote sensing, more specifically by the use of an UAV with camera, searching for the interactions between electromagnetic energy and matter. The balance between arriving radiation and radiation leaving the surface is considered as the balance of radiation to the surface, one of the elements responsible for the regulation of evapotranspiration, sensible heat flux, heat flux in the soil and photosynthesis of plants. From the data collected by the UAV, the computational tools such as the Two Source algorithm were applied, for example. The implementation of the techniques provided the necessary data for the estimation of the water balance. The information compiled in this study had as objective to provide more accurate analyzes on the documented water deficit for the vineyard.*

KEYWORDS:*Remote Sensing, Evapotranspiration, Energy Balance, Hydrological Cycle.*

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I. INTRODUCTION

The state of Rio Grande doSul is considered the main producer of grapes for processing in Brazil, with a cultivated area of approximately 50,000 ha [1]. Viticulture encompasses a significant portion of family-based farmers, and this activity is of fundamental importance for the establishment of these in the field [2]. In this context, micro-meteorological knowledge on micro-scale overlapping with local knowledge is fundamental to boost productivity and implement grape management strategies, especially when there is a growing demand for high-quality fruits, which increases the need to diagnose and implement strategies for monitoring them [3]. Monitoring the actual evapotranspiration for the conditions of the Serra Gaúcha region in southern Brazil is fundamental for the monitoring of the vineyards, as well as to support the management of the irrigation systems applied to this branch. Sustainable water management allows better use of available water resources, helping to control and optimize the use of river basin resources.

Evapotranspiration, the main component of the hydrological cycle, is the amount of water the soil-plant system loses to the atmosphere through evaporation and transpiration. This is responsible for almost all the volume of water transferred from the soil to the atmosphere. It is also very important in the release of the latent heat flux (LE), which, according to [4], is very important for different applications in studies of hydrology, agronomy and atmospheric modeling.

There are several methods of estimating evapotranspiration (ET) with high reliability, generating measurements with precision and accuracy, according to [5] and [6]. However, according to the same authors, they have limitations in estimating ET for large areas, and to map spatial variability of ET in field scales. These limitations are overcome with the use of remote sensing techniques, through radiometric data obtained by aerial or orbital imaging, since they are able to cover large areas or areas with quite hilly relief, showing the spatial variations of ET [6].

Evapotranspiration can be determined as energy balance residue. Therefore, it is possible to estimate the evapotranspiration by remote sensing, through sensors that capture the amount of radiation or sensor that directly or indirectly captures this radiation.

The estimation methods of the ET based on the energy balance through radiometric data allow the vertical latent heat flux (LE) to be obtained from radiant measurements data in the thermal infrared range. These data can be obtained by imaging, either via orbital platforms or via manned or unmanned aerial platforms.

A current example of a data acquisition platform that applies the estimation of evapotranspiration by energy balance based methods are the remotely piloted aircraft, UAV.

Due to the acquisition of very high spatial resolution of these data, ET values, soil heat flux (G), sensible heat flux (H) and Radiation balance (Rn) are estimated. This method is used by the main algorithms that use imaging data to estimate ET, such as the METRIC algorithm [5] and the Two Source algorithm adapted for the use of data from UAVs [6].

According to Ortega et al. (Two-Source Energy Balance) was developed to determine ET, based on the OSEB algorithm, with some peculiarities related to the identification of the nature of the pixels (whether soil or vegetation of interest), which determines the calculation of ET differs in two types of main targets: soil and plant crop of interest.

Thus, the present work sought to implement the estimation of evapotranspiration using remote surface sensing obtained for a characteristic vineyard area of the Rio Grande do Sul, with data obtained through UAV from the Two Source algorithm, comparing the results with reference data collected in a local agro-meteorological station.

The study area was defined in the municipality of Pinto Bandeira, located in the Serra Gaucha. This choice was due to the fact that the municipality concentrates a large part of the grape production chain in Rio Grande do Sulprovince, in addition, the city of Bento Gonçalves, headquarters of the Federal Institute of Education, Science and Technology of Rio Grande do Sul - IFRS , is close, which made possible scientific agreements for data acquisition and experimental follow-ups. For the purposes of the research, the area corresponding to the Winery (29 ° 08'48 "south latitude and 51 ° 25'33" west longitude - UTM Projection, WGS84 datum, Zone 22S) was used for data collection and validation, and Fig. 1 shows the location thereof.

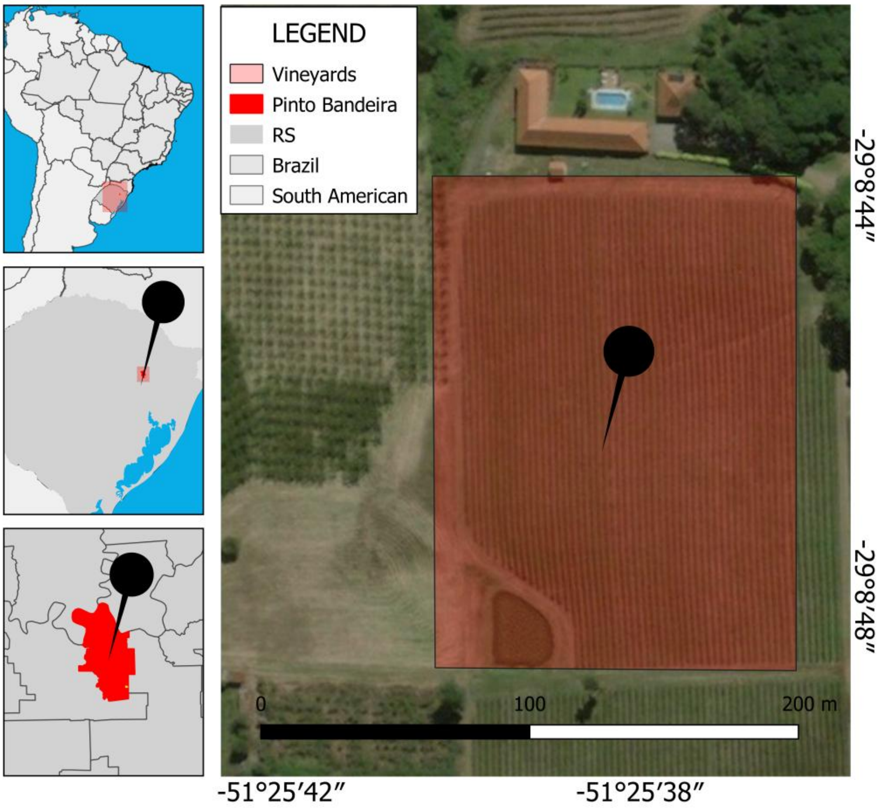

Fig. 1. Location of the vineyard.

In an ecumenical way, the Serra Gaucha region has a humid subtropical climate characterized by cold winters and mild summers [9]. It has reduced intervention of the polar systems and, the tropical marine systems

associated to the effects relief / altitude. The region reveals an abundance of annual average rainfall between 1700-2000mm, has an average temperature during the year between 14º and 23ºC, with cold months varying between 8º and 14ºC and hot months between 17º and 23ºC (type Cfb , according to the Köppen classification).
According to [10], Serra Gaucha presents a particular climate in world viticulture, due to its humid climate, warm temperate climate and temperate nights.

II. MATERIAL AND METHODS

As shown, the proposed experiment was conducted at the winery in Pinto Bandeira, Rio Grande do Sul state, located at 29º09'04 "S and 51º25'38" W and 740 meters above sea level (Figure 1). The climate is Cfb according to the Köppen classification, with an annual mean temperature of 17.6°C and annual precipitation of 1,793 mm, well distributed throughout the year[11]. The experimental area of the vineyard was installed in 2013 with the cultivars "Chardonnay" and "Pinot Noir", conducted by the "espalier" system. The vineyard density was 4545 vines per hectare, with spacing of 2.2m x 1.0m. The usual phases of the phenological phases are: budding at the end of August; flowering in October; maturation in January / February; fall leaves in April.

The ET source data considered true of field and used for comparison were obtained from the agrometeorological station installed in the experimental area of the vineyard (coordinates 29 ° 9'7.19 "S 51 ° 25'36.02" W). For the meteorological data, evapotranspiration was estimated by the Penman-Monteith method, parameterized by FAO-56 [12].

The images obtained by multispectral camera fixed to a remotely piloted aircraft based on AIBOTIX® Hexacoptero, carrying on board a Nikon CoolpixA® camera, covering the RGB and NIR bands and thermal auxiliary data from a TIRS-LANDSAT orbital image obtained for the area.
The steps that were followed to carry out the work are represented by the methodological flowchart illustrated in Fig. 2. The materials and methods used in the development of this project are discussed in sequence.

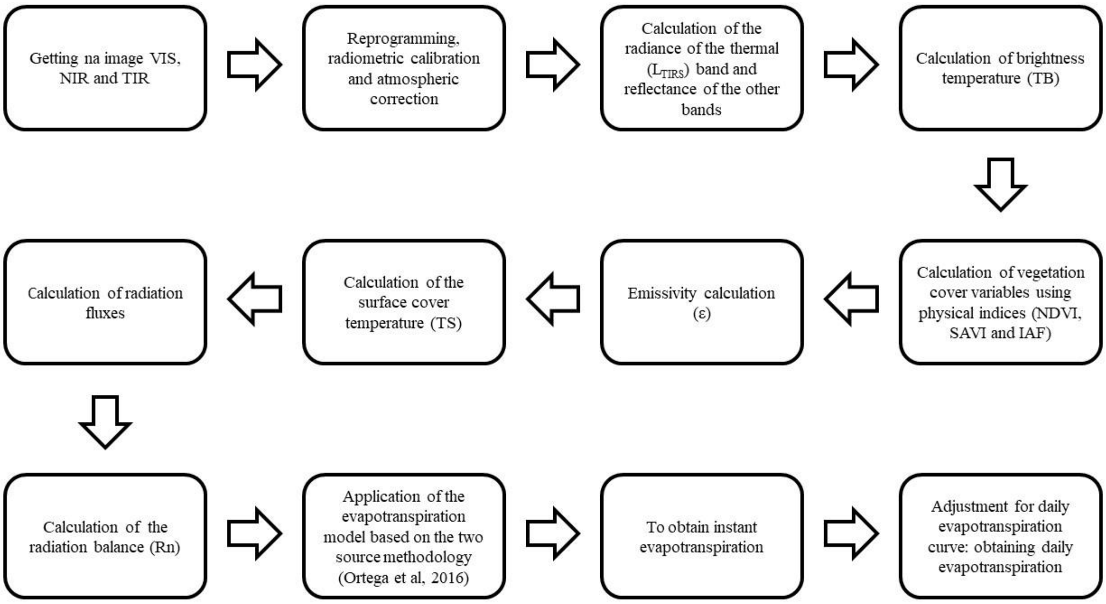

Fig. 2. Methodological flowchart

Using the QGIS © ® software, it was possible to implement the equations of the Two Source algorithm for the images. Firstly, the radiometric (and atmospheric corrections for the thermal data) were applied using the SCP (Semi-Automatic Classification Plugin) of the free software, obtaining output images representing the spectral radiance of the surface in each spectral range of interest. From this image, vegetation indexes, NDVI (Normalized Difference Vegetation Index), SAVI (Vegetation Index Adjusted to Soil Effects) and IAF (Foliar Area Index) and Brightness Temperature of surface (Tb, obtained via thermal data TIRS-LANDSAT 8). From these indices and the image data, the emissivity of the areas with vegetation and without vegetation (ε), surface temperature for areas with and without vegetation (TS_V and TS_{NV}) and albedo for areas with and without vegetation (α_V and α_{NV}), allowing the calculation of the balance of surface radiation for areas with and without vegetation (Rn_V and Rn_{NV}), soil heat flux (G), sensible heat flux for vegetated and non-vegetated areas (H_V and H_{NV}) and finally , the instantaneous latent heat flux (λET) for areas with vegetation through the equation:

$\lambda ET_V = Rn - H - G$ (eq. 1)

The λET_V was used to estimate the daily evapotranspiration, considering the latent heat of evaporation of the water as reference (water = 2.45 MJ m-2 mm-1). More details of the steps and considerations adopted can be obtained in the work of [6]. The details of the adopted methodological steps are given in sequence.

Preprocessing

With the selected images, the pre-processing tools available with the QGIS$^{©®}$ software were used, with the purpose of adjusting the data to allow the extraction of information to be used to determine the water balance and soil cover over of the study area. Each of the preprocessing steps is discussed in sequence.

Radiometric correction

In order to perform the radiometric correction in the QGIS$^{©®}$software in the scenes obtained by both the TIRS sensors and the CoolPix A camera airborne by the UAV, the gain and offset values contained in a digital file (metadata), provided with the image, were applied. With this process we obtained an output image containing the spectral reflectance of the surface.

Atmospheric correction

To perform the atmospheric correction of the auxiliary thermal data obtained through the TIRS-LANDSAT8 scene, the DarkSubtract application contained in the QGIS$^{©®}$ software was used, together with the toolbox of basic software tools. It subtracts the radiance values corresponding to a target with behavior similar to a blackbody identified in the scene.

This process can be described by Equation 2, which gives the description of obtaining the atmospheric corrected image from a scene represented in spectral radiance and the spectral radiance data corresponding to a target with a black pixel behavior (Ex: Body d ' clean and deep water or an absolute shade).

$$\mathbf{L_{-cor.} = L_{-toa} - L_{-píxelnegro}} \qquad \textbf{(eq. 2)}$$

Where $\mathbf{L_{-cor.}}$ corresponds to the atmospheric corrected radiance value for a given pixel, $\mathbf{L_{-toa}}$ indicates the radiance of the pixel to the top of the atmosphere and $\mathbf{L_{-píxelnegro}}$ indicates the reference radiance for a behavior pixel similar to a black body.

Registration

After the previous steps, as a continuity of the pre-processing, the correlation between the scenes was performed. At this stage, the purpose was to ensure spatial matching between homologous pixels of different images.

The cross-correlation algorithm was used as a way of obtaining the control points for the recording of scenes. This algorithm creates two convolution windows that run simultaneously to the base image and the image to be registered, determining statistics for each convolution window (average, median, standard deviation, etc.). When the statistics obtains the maximum coincidence between the two scenes, control points are set to the center of the convolution window. These control points were used in the spatial registration process of the scenes and as a method of resampling the cubic convolution was used.

Processing

NDVI Calculation

To calculate the NDVI on the image, we used Equation 3:

$$\mathbf{NDVI = \frac{IVP-VIS}{IVP+VIS}} \quad \textbf{(eq. 3)}$$

For each UAV imaging converted to NDVI, a monochromatic image containing normalized values between -1 and 1 was obtained as output, in which the highest values are related to the greater abundance of vegetation, and vice versa. The NDVI was used as part of the determination of the surface emissivity, LAI and SAVI, required to separate the temperature and emissivity, determination of the leaf area and vegetation adjusted to the effects of the soil, respectively.

Estimation of emissivity using NDVI data

From the NDVI images, an algorithm was used that calculates for each pixel of NDVI its emissivity, according to the following parameters proposed by the algorithm:

For $\mathbf{NDVI} \leq \mathbf{0.24}$, considered as nude soil, $\varepsilon = 0.94$;
For $\mathbf{NDVI} > 0.24, \varepsilon = 1{,}0094 + 0{,}10824.\log(\mathbf{NDVI})$.

The output image resulted in an estimated pixel emissivity. This emissivity was used as a way of adjusting the surface temperature estimates, converting the values of brightness temperature to surface temperature.

Transforming the brightness temperature into surface temperature and emissivity

In order to estimate the temperature in the soil, it was necessary to use the concept of radiant emitance, proposed by Stefann Boltzmann. For that, it is considered that the thermal radiance of a body is a result of the temperature of that body, corrected by the emissivity of the body.

In order to determine the brightness temperature (Tb) for the area, thermal radii data from the TIRS / LANDSAT 8 sensor were used, due to the lack of other thermal data available at the time. For that, thermal radival data were used, converted to brightness temperature, Eq. 4 was used which relates the spectral radiance of the thermal band with the respective brightness temperature.

$$\mathbf{Tb} = \frac{\mathbf{K_2}}{\mathbf{ln}\left(\frac{\mathbf{K_1}}{\mathbf{L-cor}}+\mathbf{1}\right)} \quad \textbf{(eq. 4)}$$

Where $\mathbf{K_1}$ and $\mathbf{K_2}$ are calibration constants corresponding to the sensor. These constants are obtained via the metadata file.

The following equations proposed by [6] were applied for the conversion of the Brightness Temperature to surface temperature in areas with and without vegetation (TS_V and TS_{NV}). 2016 (Equation 5 and Equation 6):

$$\mathbf{TS_V = \varepsilon_V.Tb_V} \textbf{(eq. 5)}$$

$$\mathbf{TS_{NV} = \varepsilon_V.Tb_{NV}} \textbf{(eq. 6)}$$

where V indicate the vegetated areas and N_V the not vegetated areas.

Calculation of radiation balance

The calculation of the radiation balance was produced in order to allow calculation of the energy balance required for the calculation of evapotranspiration. The balance of surface radiation in vegetated and non-vegetated areas is obtained using the surface energy balance equation for each of these areas (Equation 7 and 8):

$$\mathbf{R_{nV} = R_{s\downarrow} - \alpha R_{s\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1 - \varepsilon_p) R_L} \textbf{ (eq. 7)}$$

$$\mathbf{R_{nNV} = R_{s\downarrow} - \alpha R_{s\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1 - \varepsilon_p) R_L} \textbf{ (eq. 8)}$$

Where $\mathbf{R_{s\downarrow}}$ is incident short-wave radiation; α the corrected pixel albedo; $\mathbf{R_{L\downarrow}}$the long-wave radiation emitted by the atmosphere; $\mathbf{R_{L\uparrow}}$the long-wave radiation emitted by the pixel; ε_p the emissivity of the pixel.

As a result of this process step, a raster file was obtained in matrix format, containing the estimate of the radiation balance per pixel. This result was later used as an input variable for the calculation of evapotranspiration using the Two Source method [6].

III. RESULTS AND DISCUSSION

As part of the development, field surveys were carried out near the area of the Pinto Bandeira-RS winery using an AIBOTIX® brand UAV carrying a camera covering the visible and near-infrared spectral bands. The flights were performed in such a way that the height and IFOV parameters produced an average spatial resolution of 1.2 cm.

These data were orthorectified and mosaicked using PhotoScan® software. Subsequently, with the information collected by the sensors, calibration of the images and their conversion to reflectance were performed. The aerial survey images by UAV were used in the implementation of the evapotranspiration estimation algorithm defined as Two Source algorithm [6], for the vineyard of interest.

These images formed the source of feed data for the evapotranspiration algorithm, resulting in the output of radiation balance (Rn), Soil Heat Flow (G), Sensitive Heat Flow (H) and Latent Heat Flow (λET) for vegetated areas and non-vegetated areas. According to[6], we have (Equation 9):

$$\lambda \mathbf{ET} = \mathbf{Rn} - (\mathbf{G} + \mathbf{H}) \therefore \mathbf{ET} = \mathbf{3600}\frac{\lambda \mathbf{ET}}{\lambda} \text{(eq. 9)}$$

The instantaneous value of ET, converted to the mean of the hour centered at the time of collection by UAV, was obtained according to equation 10:

$$\mathbf{ET}_{inst} = \mathbf{3600}\frac{\lambda \mathbf{ET}}{\lambda} \text{(eq. 10)}$$

Where, $\mathbf{ET_{inst}}$ is the instant ET value, 3600 is the conversion time from seconds to hours, λ **ET** is the instant latent heat flux chart and is the λlatent heat of water vaporization (2.45 x 106Jkg $^{-1}$). As results, images representing each of these variables were obtained (Fig. 3, Fig. 4 and Fig. 5).

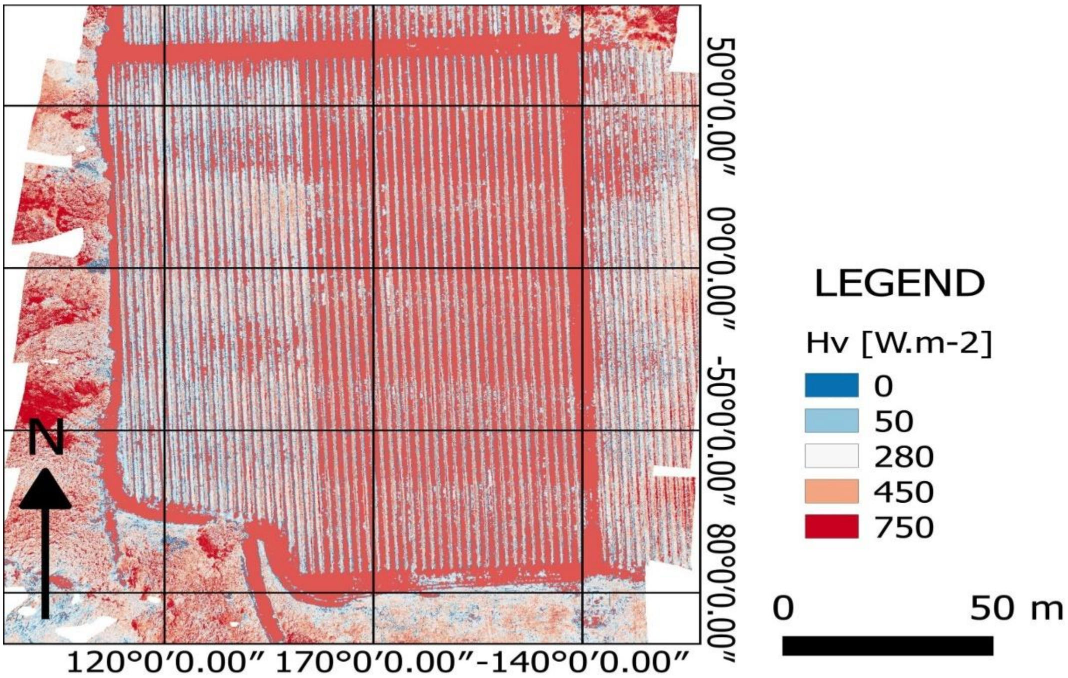

Fig. 3. Vegetation sensitive heat flow (H)

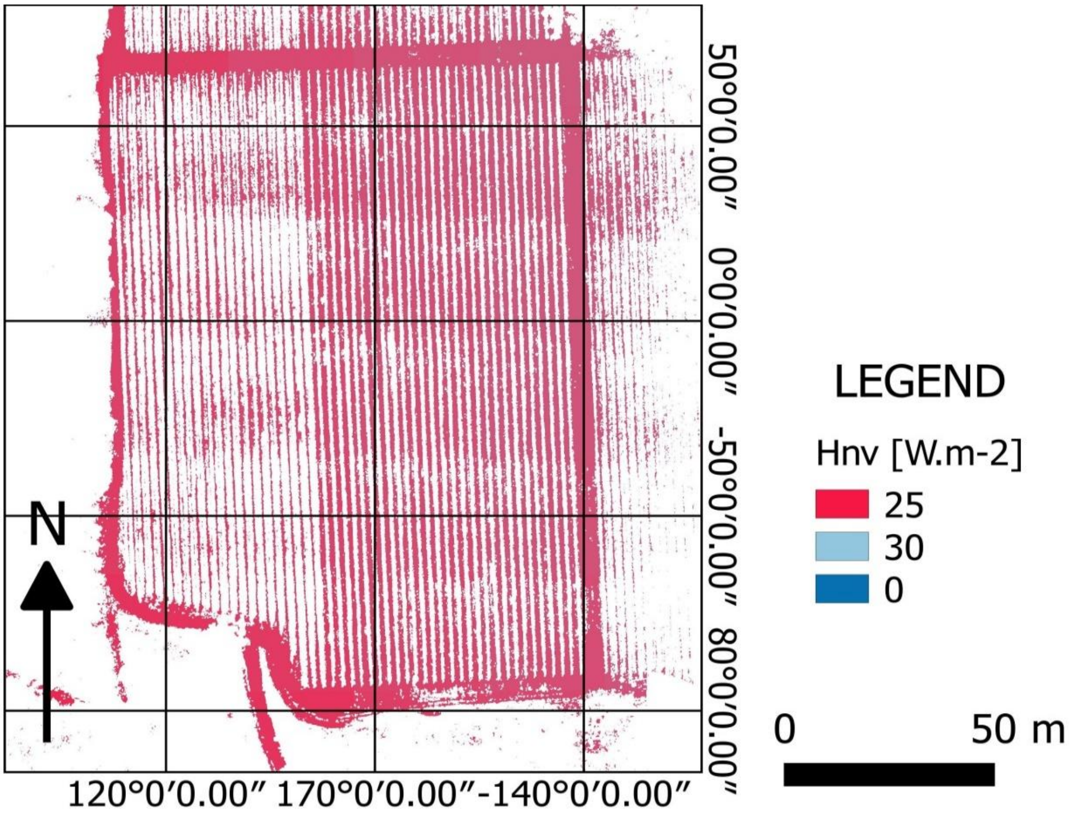

Fig.4. No vegetation sensitive heat flow (H)

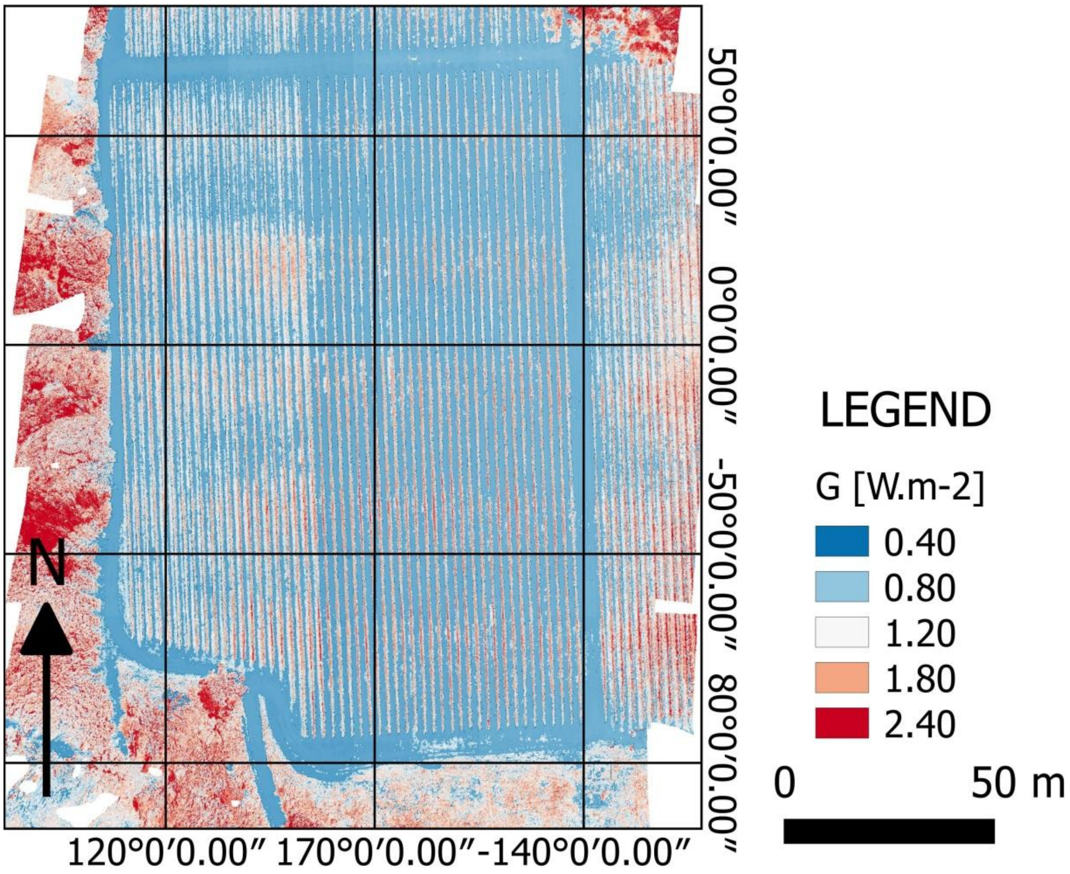

Fig.5. Heat flux in soil (G)

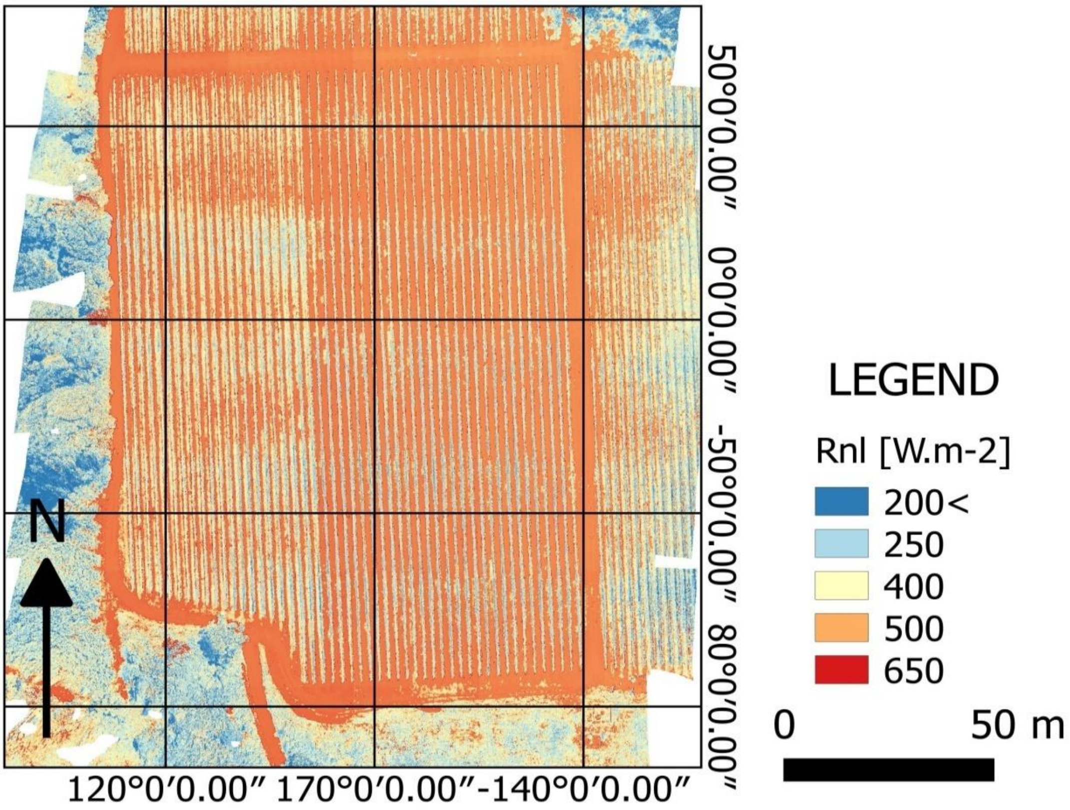

Fig.6.Total radiance balance (Rn_T)

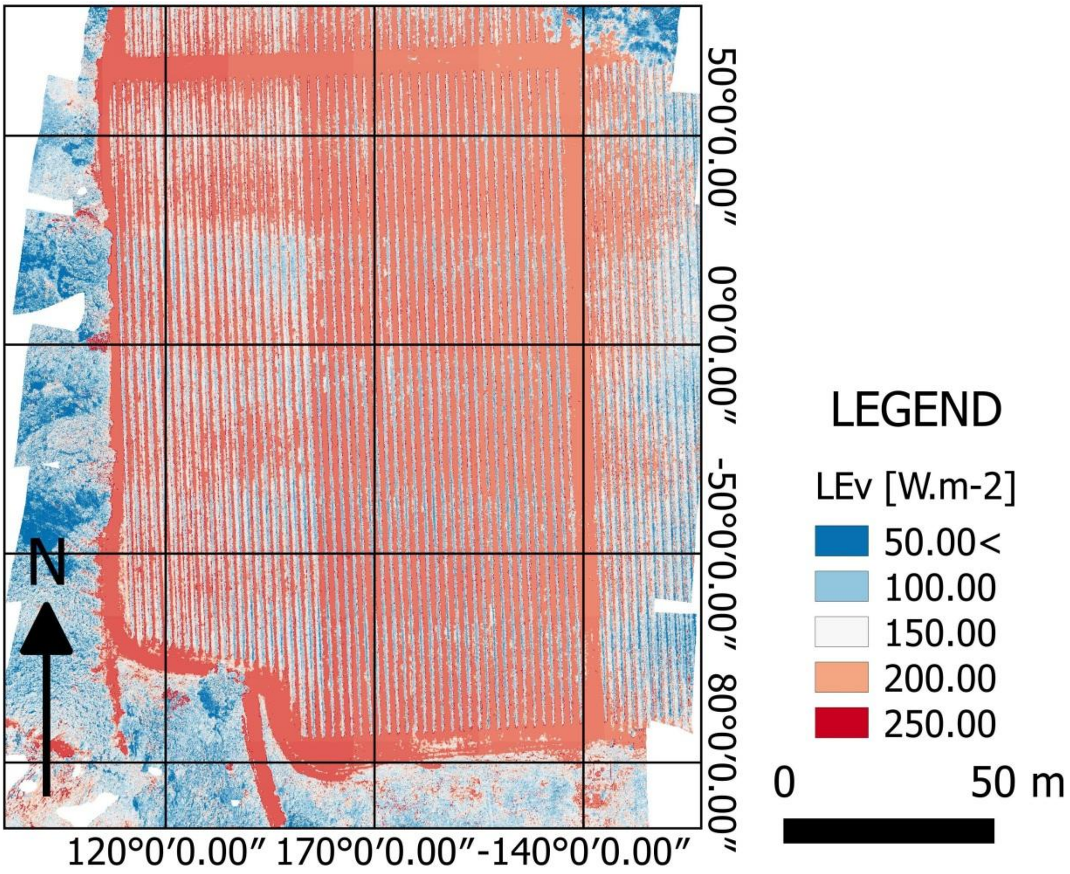

Fig.7.Vegetation latent heat flux (λET_V)

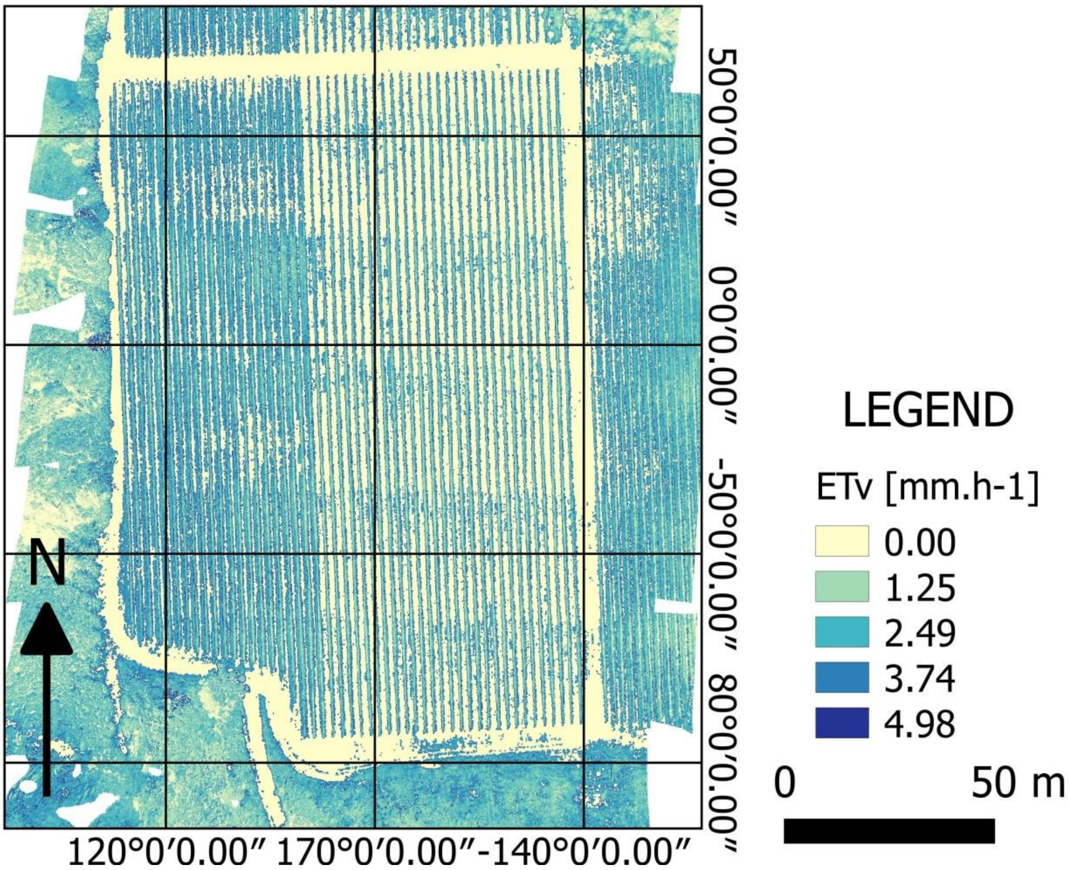

Fig.8.Daily evapotranspiration (ET_V)

Preliminary values determined spatial oscillations of water balance, being in agreement with that described by the agronomist responsible for the area. Statistical analyzes and larger comparisons are necessary and will be performed with the treatment of new data that has been continuously collected for the following crop years.

As a way of evaluating the results, the estimated data were compared with the evapotranspiration data (daily ET, Table 1) calculated by the Penman-Monteith method using data from the meteorological station near the experimental area for the months of January and February/2017, corresponding to the period of the surveys presented.

Table 1. ET for the months of January and February of 2017 calculated from the meteorological station data by the Penman-Monteith method

January				February			
day	**ET (mm.dia-1)**	**day**	**ET (mm.dia-1)**	**day**	**ET (mm.dia-1)**	**day**	**ET (mm.dia-1)**
01	3.78	17	3.63	01	1.49	17	2.46
02	2.88	18	4.86	02	1.63	18	2.33
03	4.64	19	5.56	03	2.27	19	1.82
04	2.91	20	5.37	04	2.56	20	2.09
05	2.37	21	4.31	05	1.38	21	1.83
06	2.70	22	5.02	06	2.22	22	1.85
07	3.17	23	4.51	07	2.39	23	1.28
08	4.06	24	5.15	08	2.01	24	1.14
09	1.83	25	3.16	09	2.33	25	1.71
10	3.02	26	1.69	10	2.06	26	2.11
11	2.91	27	3.54	11	0.66	27	2.04

12	5.66	28	5.36	12	1.56	28	1.75
13	5.83	29	3.01	13	1.33		
14	3.51	30	3.06	14	1.16		
15	5.53	31	3.24	15	1.81		
16	3.02			16	2.16		

Figure 5 shows ET estimated from the orbital image using the Two Source algorithm in scenes obtained by UAV (complemented with a TIRS-LANDSAT 8 thermal scene). On January 13, 2017, we can compare data from both sources, 5.83 mm d-1 of the meteorological station (Table 1) and 6.29 mm d-1 of the result image (pixels near the station point), a difference of 0.46 mm d -1 or 7.9%.

Using LANDSAT 8 sensor imaging data to map water use in the Colorado River Basin (USA), [13] found a clear advantage in the use of Landsat images for ET mapping, allowing quantification of water use at scale of field, with time frequency cost and reduced problems with cloud cover, which we also experimented during this brief study. Of the three images downloaded for this cycle, only one could be used because of the cloud coverage on the study site.

These issues can be overcome by using UAVs, which have a much better resolution (spatial and temporal), allowing a better estimation of the water needs of a crop, for example. [6], using UAV to estimate energy balance on drip irrigated olive orchards, also found that multispectral and thermal cameras in UAVs can provide tools to evaluate the effects of spatial variability of energy balance components on heterogeneous orchards, such as vineyards, which have different plant densities and fractional coverages.

Also mentions the best image resolution, [14] provided by the reduced flight altitude, as the major advantage of UAV images. On the other hand, their downside is that they need more flights to cover large areas. In this study, as the area was not large (1.6ha), it took two flights at an altitude of 40m to cover the entire area.

IV. CONCLUSION

The present work listed a practical example for the estimation of evapotranspiration through the water balance for the region of the Winery, in the city of Pinto Bandeira in the Serra Gaucha. The extraction of the information necessary for the water balance, using the Two Source model, showed that the differentiated analysis of the soil cover independently for exposed soil and cultivated areas, advances in bringing better results on the target of interest.

However, the geoprocessing tools that were used to perform this research were fundamental for data generation that enabled the production of information to evaluate the evapotranspiration dynamics in micro-spatial scale. This work aimed to constitute a reference and familiarization material for a model for the estimation of evapotranspiration in vineyards from UAV imagery.Finally, it is suggested a new analysis to be carried out taking into account the already structured evapotranspiration models for the differentiated approach of the vegetation and the soil as the presented Two Source model [6] in follow-up climatic seasonality and variations keeping the consideration of only the areas occupied by the vegetation, disregarding the soil without vegetation, seeking to relate the data obtained with the model in comparison with field data obtained by agrometeorological stations to be installed.

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