International Journal of Applied Earth Observation and Geoinformation 28 (2014) 160–169

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Estimation of real evapotranspiration and its variation in Mediterranean landscapes of central-southern Chile

L. Olivera-Guerra[a,*], C. Mattar[a], M. Galleguillos[b]

[a] Laboratory for Analysis of the Biosphere (LAB), University of Chile, Avenida Santa Rosa 11315, La Pintana, Santiago, Chile
[b] Department of Environmental Sciences, School of Agronomic Sciences, University of Chile, Avenida Santa Rosa 11315, La Pintana, Santiago, Chile

ARTICLE INFO

Article history:
Received 25 September 2013
Accepted 21 November 2013

Keywords:
Evapotranspiration
Rainfed landscape
S-SEBI
ASTER

ABSTRACT

Evapotranspiration (ET_d) is a key controller in the ecohydrological processes of semi-arid landscapes. This is the case of the dry land in Chile's central-southern zone, where forestry, farming and livestock activities must adapt to precipitation with considerable year-on-year variations. In this study, the spatial distribution of ET_d was estimated in relation to the land use map and physical parameters of the soil. The ET_d was estimated through the Simplified Surface Energy Balance Index (S-SEBI) using data from weather stations and remote data provided by the ASTER and MODIS sensors for November 2004 and 2006, respectively. The spatial variability of ET_d was compared among different plant types, soil textural classes and depths using non-parametric statistical tests. In this comparison, the highest rates of ET_d were obtained in the forest covers with values of 7.3 ± 0.8 and 8.4 ± 0.8 mm d^{-1} for 2004 and 2006, respectively. The lowest values were estimated for pastures and shrublands with values of 3.5 ± 1.2 mm d^{-1} and for crops with rates of 4.4 ± 1.6 mm d^{-1}. Comparison of the ET_d of the native forest covers and plantations of exotic species showed statistically significant differences; however, no great variation was noted, at least in the study months. Additionally, the highest rates of ET_d were found in the clay loam textures (6.0 ± 1.8 and 6.4 ± 2.0 mm d^{-1}) and the lowest rates in the sandy loam soils (3.7 ± 1.6 and 3.9 ± 1.6 mm d^{-1}) for 2004 and 2006, respectively. The results enable analysis of the spatial patterns of the landscape in terms of the relation between water consumption, ET and the biophysical characteristics of a Mediterranean ecosystem. These results form part of the creation of tools useful in the optimization of decision-making for the management and planning of water resources and soil use in territories with few measuring instruments.

1. Introduction

Evapotranspiration (ET_d) is a key component in the processes that guide the interactions of water and energy in semi-arid ecosystems. The water balance in these ecosystems is regulated by solar radiation and pluviometric events characterized by their low frequency and varied intensity, causing moisture in the soil that restricts soil-plant-atmosphere interactions. Under these conditions, ET_d represents a large proportion of the water budget, estimated at more than 70% of incoming precipitation (Kurc and Small, 2004; Huxman et al., 2005; Breshears, 2006; Moussa et al., 2007). In such landscapes, the soils store the incoming water from precipitation for potential biological activity (Huxman et al., 2004). This means that the variation in the availability of water resources is closely linked to changes in the physiological and structural states of the vegetation, which may be important in the control of ecological processes. Accordingly, ET_d is the central controller in ecohydrological processes in semi-arid environments, such as productivity of the ecosystem (Huxman et al., 2005; Yepez et al., 2005) and the influences of the vegetation on the water and the energy exchange (Moreira et al., 1996). Despite advances in the understanding of these phenomena, it has not yet been fully documented how the surface and subsurface characteristics of the soil can modify water and energy flows.

The Mediterranean landscape in Chile's central-southern zone is characterized by vast expanses of forest plantations and rainfed agricultural crops, mainly wheat, that must adapt to the rain cycles, which are scarce, intermittent and with significant year-on-year variations, as is frequently the case in semi-arid contexts (Newman et al., 2006). In addition to the water limitations during the dry season due to the absence of precipitation, water availability problems have intensified in recent decades. This is due to an increase in the demand for water for agricultural uses and human consumption (Lara et al., 2003), which may be critical in future

* Corresponding author. Tel.: +56 229785728.
E-mail address: luis.enrique.olivera@gmail.com (L. Olivera-Guerra).

0303-2434/$ – see front matter
http://dx.doi.org/10.1016/j.jag.2013.11.012

scenarios given the climate change trends that project a decrease in precipitation and an increase in temperature in these territories (Fuenzalida et al., 2006).

Moreover, this zone has undergone strong man-made modifications, a product of the expansion of plantations of exotic forest species (mainly *Pinus radiata*), which has led to the elimination of extensive areas of native forest. This decrease has been estimated at 67% of the initial surface of native forest between 1975 and 2000 (Echeverria et al., 2006). These modifications in soil use and forest cover are important variables to consider in the hydrological cycle, and these have been studied regarding their effect on ET_d and water consumption (Bosch and Hewlett, 1982; Iroumé and Huber, 2002; Iroumé et al., 2006; Huber et al., 2008, 2010; Birkinshaw et al., 2011). Huber et al. (2008) reported greater water consumption (ET_d) on plantations of exotic species (*P. radiata* and *Eucalyptus* spp.) than on pasture and shrublands. These works focused mainly on catchment basins of less than 100 ha due to the greater control in the samplings, which increases their likelihood of success given that areas with fragmented landscape and reliefs could bias the results (Bosch and Hewlett, 1982). By contrast, in catchment basins of 100–1000 km^2, Pizarro et al. (2006) and Little et al. (2009) documented a decrease in the production of water flows due to the growth of forest plantation covers of exotic species to the detriment of the native forest.

Therefore, it is relevant to conduct studies on the spatial distribution patterns of ET_d and its relationship with various land use maps. Therefore, determining how ET_d is related to this information contributes to the understanding of processes that explain landscape hydrology, particularly on vast expanses and at a territorial level in the central-southern zone of Chile.

Surface energy balance models based on satellite images have successfully been applied to estimate the spatial distribution of ET_d in various landscapes. The Simplified–Surface Energy Balance Index (S-SEBI) (Roerink et al., 2000) is an algorithm that can estimate energy flows and ET_d through spatial contrasts between captured hydrological conditions and the information from satellite images regarding surface reflectance and the thermal region of the spectrum. This model requires a minimum of meteorological data, adapting to zones with few measurements in situ or that simply do not have these measurements. The S-SEBI model has been widely applied and evaluated successfully in obtaining the ET_d with different satellite sensors on an wide variety of ecosystems and at different spatial scales (Roerink et al., 2000; Gomez et al., 2005; Sobrino et al., 2005, 2007, 2008; Verstraeten et al., 2005; García et al., 2007, 2008; Boronina and Ramillien, 2008; Galleguillos et al., 2011; Mattar et al., 2013) on flat as well as mountainous terrains.

The spatial estimation of ET_d has been of interest to evaluate the characteristics of the landscape serving as an indicator of the water deficit of the surface (García et al., 2007, 2008), in the classification of functional types of ecosystems (Fernández et al., 2010), in the modeling of soil attributes (Taylor et al., 2013), and in the characterization of types of soil cover (Pôças et al., 2013).

Considering the aspects analyzed previously and the biophysical variables of the landscape that affect water consumption, the main objectives of this study focus on the dry landscape of the central-southern zone of Chile, (i) to evaluate the spatial distribution of ET_d in relation to the different land use maps and physical variables of the soil that determine the water storage capacity available for plants and (ii) to analyze the relevance of using ET_d to improve the understanding of spatial patterns throughout the territory.

The manuscript is structured as follows: Section 2 describes the study area, the data used and the methodology of this work. Section 3 presents the results and discussions on obtaining the spatial distribution of ET_d and its comparison with the biophysical variables associated with the vegetation and the physical properties of the soil. Finally, Section 4 presents the conclusions.

2. Data and methodology

2.1. Study area

The study area is two zones of the semi-arid sector of the Maule Region in central-southern Chile, located between 35°00′ and 35°50′ S, which cover a total area of 6050 km^2. This landscape has been drastically modified in recent decades due to a great expansion of plantations of exotic forest species (mainly of *P. radiata*), which led to the elimination of extensive areas of native forests (San Martín and Donoso, 1997), where Echeverria et al. (2006) estimated an annual reduction in native forest at a rate of 4.5%. The heavy development of forest activity has relegated the native forests to small patches (<100 ha) of secondary forests comprised mainly of *Nothofagus* (*N. obliqua* and *N. glauca*) and sclerophyll species such as *Acacia caven*, *Quillaja saponaria* and *Maytenus boaria* (Echeverria et al., 2006).

The area presents a Mediterranean climate with winter rains and a prolonged dry season between 7 and 8 months. Annual precipitation varies between 600 and 900 mm per year, concentrated mainly between May and August. The potential evaporation during the summer months is between 200 and 500 mm, exceeding the scarce rain. This zone is described by Little et al. (2009) as a semi-arid zone; however, according to the criteria of De Pauw et al. (2000) it is a sub-humid zone. In spite of this, the climatic conditions make the zone subject to a significant water deficit, which is critical in the dry season, with low cloud cover and high luminosity. These conditions enable the development of rainfed crops in the study area, mainly wheat, which must adapt to the scarce, intermittent rain cycles that vary considerably year-on-year.

To ascertain the topography of the terrain in the study area, a digital elevation model (DEM) was used via the ASTER GDEM, which has a spatial resolution of 30 m. This product was developed jointly by NASA and the Japanese Ministry of Economy, Trade and Industry (METI) and is freely available at http://www.gdem.aster.ersdac.or.jp/. The DEM was used to generate the slope and exposure maps needed to estimate solar radiation. In Fig. 1, an infrared composition appears on the DEM in the study area.

2.2. Spatial remote data and GIS

Two ASTER Level-2 product scenes were used of surface reflectance (AST-07), bands of surface emissivity (AST-5) and surface temperature (AST-08), which already have radiometric and atmospheric corrections (Abrams, 2000). The images of surface reflectance corresponding to the bands in the visible (Vis) and near infrared (NIR) were obtained at 15 m pixels, the bands in the shortwave infrared (SWIR) were obtained at 30 m pixels, while the products AST-5 and AST-8 corresponding to the bands in the thermal infrared (TIR) were obtained at 90 m pixels. The two scenes were acquired for November 5 2004 and November 18 2006 around 3 p.m. UTC (12 p.m. local time) under clear skies. The two scenes correspond to the period of maximum vegetation growth, where there are conditions of high radiation as well as optimal conditions in terms of water availability in the soil, this being immediately after the months where most of the rain is concentrated. Indeed, it has been shown in studies on Mediterranean ecosystems (Galleguillos et al., 2011) that during the spring-summer months the spatial differences of ET_d are maximized when there is a water deficit of varying magnitudes in the vegetation caused by the progressive exhaustion of the water reserves in soils. This phenomenon has greater impact on soils with physical properties that involve a lower retention capacity and subsequent delivery of water to the plants.

For the ASTER scenes, the Normalized Difference Vegetation Index (Rouse et al., 1973; Tucker, 1979) was calculated using the