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An operational method for the disaggregation of land surface temperature to estimate actual evapotranspiration in the arid region of Chile

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ABSTRACT

Monitoring evapotranspiration in arid and semi-arid environments plays a key role in water irrigation scheduling for water use efficiency. This work presents an operational method for evapotranspiration retrievals based on disaggregated Land Surface Temperature (*LST*). The retrieved *LST*s from Landsat-8 and MODIS data were merged in order to provide an 8-day composite *LST* product at 100 × 100 m resolution. The method was tested in the arid region of Copiapó, Chile using data from years 2013–2014 and validated using data from years 2015–2016. In-situ measurements from agrometeorological stations such as air temperature and potential evapotranspiration (*ET0*) estimated at the location were used in the ET estimation method. The disaggregation method was developed by taking into account (1) the spatial relationship between Landsat-8 and MODIS *LST*, (2) the spatial relationship between *LST* and the Normalized Difference Vegetation Index (*NDVI*) at high spatial resolution (Landsat-8), and (3) the temporal variations along the year of both relationships aforementioned. The comparison between disaggregated *LST* at 100 m resolution and in situ *LST* measurements presents a coefficient of determination (r^2), in average, equal to 0.70 and a RMSE equal to 3.6 K. The disaggregated *LST* was used in an operational model to estimate the actual evapotranspiration (*ETa*). The *ETa* shows good results in terms of seasonal variations and in comparison to the evapotranspiration estimated by using crop coefficients (*kc*). The comparison between remotely sensed and in situ *ETa* presents an overall r^2 close to 0.67 and a RMSE equal to 0.6 mm day^{-1} for both crops. These results are important for further improvements in water use sustainability in the Copiapó valley, which is currently affected by high water demand.

1. Introduction

Evapotranspiration (*ET*) is one of the most important parameters of the hydrological cycle affecting water availability on the Earth's surface. During the last decades, several works have been documented the critical importance of ET for agricultural irrigation scheduling (Porter et al., 2012; Senay et al., 2013), water resource availability (Oki and Kanae, 2006), hydrologic and meteorological forecasts (Findell et al., 2011) and climate change scenarios related to drought indexes (Gao et al., 2011). ET estimations are also crucial for management of water resource in areas of water scarcity since the actual rate of water use by vegetation can deviate significantly from potential ET rates (as regulated by atmospheric demand for water vapor) (Anderson et al., 2012). Thus, detailed spatial and temporal maps of ET provide power tools for decision makers and enable managers to more judiciously allocate available water for agricultural, urban, and environmental uses.

To estimate and quantify ET, it is necessary to account for diverse meteorological observations and land surface parameters such as the land surface temperature (LST). LST modulates the surface energy fluxes and it is key to estimating ET for monitoring crop water demand (Kalma et al., 2008; Li et al., 2009; Zhan

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et al., 2013; Cammalleri et al., 2014). In agricultural and heterogeneous natural systems, high variability of ET and LST can occur at scales of hundreds of meters or less. Thus, moderate-resolution satellite Thermal Infra Red (TIR) imagery is therefore required and essential to identify and fully understand water use and water availability at the field scale associated with specific crop types (Anderson et al., 2012; Senay et al., 2016).

The combination of *LST* and vegetation indexes at several time and spatial scales has been proven as a potential technique to disaggregate *LST* (DLST) to determine crop *ET*. Several *DLST* methods have been proposed in recent decades using various information sources available at low, medium or high spatial resolution, which are widely detailed in Zhan et al. (2013). Nevertheless, the Normalized Difference Vegetation Index (NDVI) based methods are still the most used operational approaches due to the availability of data at high spatio-temporal resolution. For instance, ALEXI, DisALEXI, DisTrad, TsHarp, among other algorithms (Kustas et al., 2003; Anderson et al., 2004; Agam et al., 2007; Bindhu et al., 2013; Cammalleri et al., 2014; Mukherjee et al., 2014).

Some variations of the NDVI based methods including phenology such as the robust disaggregation procedure proposed by Merlin et al. (2010, 2012) which account for the senescent vegetation fraction and soil moisture in addition to *NDVI*. These methods require additional parameters such as soil moisture, albedo, soil and vegetation temperatures, among others, which might be difficult to implement in an operational structure. There are other simple methods based on a subtraction approach that merge the spatial detail of higher-resolution imagery with the temporal change observed in coarser or moderate-resolution imagery (Hong et al., 2011; Kim and Hogue, 2012). The methods mentioned above can be applied to *ET* or soil moisture retrievals in order to estimate the surface energy balance (*SEB*) at better spatial resolutions, as well as to crop water management (Sobrino et al., 2012; Mattar et al., 2014). However, DLST method must be adapted over arid zones where high seasonal phenology in addition to thermal amplitude is evidenced in large areas.

Remote Sensing monitoring of semi-arid or arid regions target cultivated areas surrounded by barren conditions (e.g. deserts) which can impact on *DLST* and therefore in *ET* quantification. The proportion of bare soil observed in a given pixel during a year can affect the crop vegetated fraction increasing the *LST* and affecting *ET* and water requirements. Hence, *DLST* approaches concerning the spatial resolution over arid or semi-arid regions by using operational methods should be capable to monitor crop water consumption and usage accounting the seasonal variations. Despite the fact that there are some works on complex heterogeneous and semi-arid regions (Zhu et al., 2010; Weng et al., 2014), these methods are not simple in their application and present shortcomings in the operational mode such as the use of search windows to select similar pixels and to perform a sensitivity analysis before modeling (Weng et al., 2014).

In Chile, a persistent rainfall deficit has prevailed in the central zone since 2010 leading with a decline in water reservoirs generating a megadrought without precedents (Boisier et al., 2016). In the arid region of Chile, such as the Copiapó valley, the water resources availability has declined in addition to the water demand owing to agricultural and mining activities. The arid region of Copiapó is one of the most important agricultural areas of Chile and demands large amounts of water (4856 L/s equal to 59% of the total demand in the Copiapó; Bravo, 2013). Thus, it is of crucial importance that the water demand be determined and monitored and the water use efficiency be improved in this zone. Therefore, the main objective of this work is to present an operational *DLST* approach for estimating the actual evapotranspiration (*ETa*) over an arid or semi-arid region in Chile. This manuscript is structured as follows: Section 2 presents the study area and data. Section 3 describes the method proposed in this work. Section 4 presents the results and analysis and finally, Sections 5 and 6 provide the discussion and conclusions, respectively.

2. Study area and data sets

2.1. Study area

The study area belongs to the Copiapó Valley located in the arid region of Atacama, Chile. The whole valley has an area of about 18538 km^2 divided in longitudinal sectors from the Los Andes Highlands (sector 1) to the coast (sector 6) (Fig. 1). The study area has a surface of about 1670 km^2, and is located in the flat lands of sectors 5 and 6. It is an agricultural area mainly covered by olives, vineyards, pomegranates and natural vegetation (Fig. 1). The climate is semi-arid to arid with low mean annual precipitation (28 mm) and hot and dry summers (December, January and February), which coincide with the vineyard's growing season, and cold and dry winters (June, July and August). Despite the Copiapó Valley's proximity to the Atacama Desert, the zone located in sector 5 and 6 is highly covered with clouds for several days per year, which might affect the *ETa* measurements and the availability of optical remote sensing imagery. In terms of water resources, the Copiapó Valley is characterized by acute water scarcity mainly attributed to the low annual precipitation and the systematic stress put onto the aquifer by water consumers, mainly agriculture and mining (Oyarzún and Oyarzún, 2011; Valdés-Pineda et al., 2014; Suarez et al., 2014). This situation has brought about the Copiapó Valley's current critical situation, resulting from the extraction of water in recent decades, which has risen to rates greater than the natural replenishing of the aquifer (demand equal to 8222 L/s over a replenishing equal to 6347 L/s; Bravo, 2013), thus increasing the pressure for water resources and generating a new regional scenario for water use efficiency.

2.2. In situ data

In this work, in situ data derived from meteorological stations generated by the "Grupo de Estudios del Agua (GEA)" (www.agroclima.cl), in addition to LAB-network (here in-after LAB-net) (Mattar et al., 2016) data sets, were used. The GEA meteorological data sets were provided by 12 meteorological stations in the Copiapó Valley, four of which are located in the study area of this work. These stations were located in vineyards and olives orchards, and they provide basic meteorological parameters. The reference evapotranspiration (*ET0*) from ASCE standardized of a short crop and air temperature (*Ta*) between January 2013 and December 2014 were processed from the GEA network and used in this work.

In addition, in order to complement the GEA meteorological stations, data from two meteorological and radiative flux stations from LAB-net were also used. To this end, *ET0*, *Ta*, *infrared thermal, global and net radiation* (*Rg*, *Rn*) provided at olive orchards and vineyards crops were processed between July 2014 to December 2014, totaling 6 stations in the study area. These stations were used to generate the calibration and the partial evaluation of the *ETa* retrieval approach. On the other hand, LAB-net data from years of 2015 and 2016 was used to validate the *DLST* and *ETa*. The LAB-net station over olives orchards is located in a plot of land measuring about 17 hectares with a fraction vegetation cover of 25% distributed uniformly. Whereas the LAB-net station over vineyards is located in an area of 28 hectares with a homogeneous fraction vegetation cover.