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The EUMETSAT Network of Satellite Application Facilities
LSA SAF Land Surface Analysis

Validation of reference crop evapotranspiration derived from geostationary satellite MSG using in situ data from Andalusia (Spain)

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ABSTRACT

The main objective of this study was to validate the incoming solar radiation data and the reference crop evapotranspiration (ET_o) developed in the framework of EUMESAT's Satellite Application Facility (SAF) on Land Surface Analysis (LSA) (Trigo et al., 2010), using accurate values measured from a quality controlled weather station network. Thus, it has been developed a procedure of calibration and validation in order to check the capability of the LandSAF products to provide accurate reference ET_o values for wide areas. For this task meteorological data from the Agroclimatic Information Network of Andalusia (RIA), a weather station network located at Southern Spain, has been used. The data collected by these stations underwent further scrutiny. Measured solar radiation was compared with theoretical radiation (expected values) in clear sky conditions (adjusting the transmissivity for each weather station) and with other neighboring stations. After this validation process, 57 stations were included in the study, where the incoming solar radiation and ET_o values estimated from LandSAF using a new revised Makkink equation were compared. The comparison results indicated that there were very good correlations between estimated and measured radiation values (average R^2 and RMSE values were equal to 0.96 and 1.77 MJ/m^2, respectively). The comparison between ET_o estimated using the new revised Makkink equation and that estimated using Penman-Monteith equation using the validated weather station data provided equally very good results with R^2 and RMSE values of 0.91 and 0.74 mm day^{-1}, respectively. These results indicate that the described methodology is able to provide very accurate incoming solar radiation and ET_o values for wide areas with different climatic conditions in a very efficient way.

INTRODUCTION

The method proposed by Allen et al. (1998) in the FAO-56 paper to determine evaporative demands of agricultural crops is currently considered one of the most accurate procedures. It is based on the concept that crop water requirements can be estimated from the reference crop evapotranspiration, ET_o, multiplied by a crop-factor. ET_o is the evapotranspiration under the given meteorological conditions from an extensive hypothetical grass crop with specified characteristics. The methodology concerns the application of a version of the Penman-Monteith equation (PMFAO56, Allen et al., 1998) and it requires input data collected over a horizontal extensive surface previously described, although such sites are rare in most semi-arid regions. Due to these limitations, a new procedure to determine reference crop evapotranspiration has been developed in the framework of EUMESAT's Satellite Application Facility (SAF) on Land Surface Analysis (LSA), and has provided very satisfactory results (de Bruin et al., 2010). The objective of this study is to validate the LandSAF approach to estimate ET_o from geostationary satellite images and additional information provided by operational weather forecasts from the European Centre for Medium-range Weather Forecasts (ECMWF) considering a weather station network located in Andalusia, Southern Spain composed by around 100 weather stations located under different weather conditions.

MATERIAL AND METHODS

The Agroclimatic Information Network of Andalusia (RIA) is composed by 100 weather stations located in the main irrigated areas of Andalusia. This network provides semihourly and daily data of the main meteorological variables (relative humidity and temperature of the air, global radiation, wind speed and direction, rainfall and ET_o using Penman-Monteith equation). The weather data provided by the RIA are validated following the procedures described in Estevez et al. (2011). Thus, measured solar radiation is compared with theoretical radiation (expected values) in clear sky conditions (adjusting the transmissivity for each weather station) and with other neighboring stations.

For ET_o estimation using LandSAF methodology, it is required daily values of downward solar radiation (DSSF) obtained from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) radiometer onboard Meteosat Second Generation (MSG) and the air temperature at 2 m extracted from ECMWF initial fields. These data are applied to a revised Makkink approach proposed by de Bruin et al. (2010), calibrated to the regional conditions of Southern Spain (Fig. 1), developing an empirical formula to estimate ET_{oMSG} using the solar radiation, R_{sMSG}, (LSA SAF, DSSF product) and ECMWF 2m air temperature,-T_{ECMWF}. The two empirical constants *a* and *b* of the revised Makkink formula (de Bruin et al., 2012) were fit using ET_o values measured by a lysimeter grass at Cordoba, Southern Spain, for 2008.

$$ET_{0\,MSG} = (aT_{ECMWF} + b)R_{s\,MSG}$$

To carry out the validation of LandSAF procedure, a comparison between daily solar radiation and ET_o provided by the RIA and LandSAF was carried out for 57 weather stations located in Southern Spain (Fig. 1) during the years 2007, 2008 and 2009.

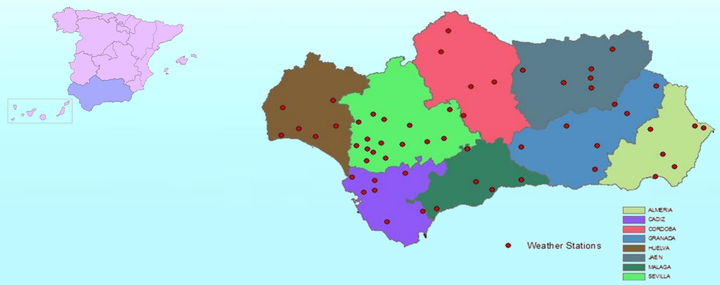

Figure 1. Spatial distribution of the weather stations used in the study.

RESULTS

For the period 2007 - 2009 we compared the daily solar radiation and ET_o (using the new Makkink approach) from LandSAF (Fig. 2) with the corresponding values measured by 57 weather station included in the RIA. The results describing average RMSE, coefficient of determination and slope are shown in Table 1 and, in general, were very satisfactory. Due to wind effects and inland location of some weather stations for some of them the obtained results were less satisfactory (Chiclana de Segura, Jaen (2008): ET_o R^2=0.90 and slope =0.85; Loja, Granada (2009): ET_o R^2=0.94 and slope =0.88 and Estepona, Malaga (2007): ET_o R^2=0.83 and slope =0.94) and further studies must be focused on this direction.

Considering a representative weather station as Cordoba (Fig. 3), LandSAF estimates of solar radiation (Rs) compare fairly well with the *Rs* from RIA (R^2= 0.93 and slope of linear regression 0.99) for all the analyzed period (2007-2009).

For the same representative weather station of Cordoba, daily ET_o determined with PMFAO56 (Fig. 4) for the analyzed period is compared with ET_o determined with the new approach of Makkink using MSG incoming solar radiation and temperature at 2 m provided by ECMWF model. Results show a good behavior of the Makkink approach compared with ETo measured value. Considering previous studies (Gavilán et al., 2008) for arid and windy weather stations, the Makkink formula could required local-regional calibration and will be analyzed in further studies.

Table 1. Summary of statistics from comparison between estimated solar radiation and ET_o using LandSAF and measured values from the Agroclimatic Information Network of Andalusia (RMSE: root mean square error; R^2: coeficient of determination; RE: relative error).

	Maximum	Minimum	Average	Standard Deviation
Radiation by RIA (MJ/m^{2}day)	20.2	16.6	18.4	0.58
Radiation by LandSAF (MJ/m^{2}day)	20.3	16.0	18.2	0.55
ET_o by RIA(mm/day)	4.7	3.1	3.8	0.26
ET_o by LandSAF (mm/day)	3.8	2.7	3.5	0.21
RMSE-Radiation (MJ/m^{2}day)	3.71	1.21	1.77	0.34
R^2-Radiation	0.99	0.79	0.96	0.02
Slope-Radiation	1.04	0.80	0.99	0.03
RE-Radiation (%)	21.8	6.7	9.7	0.02
RMSE-ET_o (mm/day)	1.13	0.45	0.74	0.15
R^2-ET_o	0.96	0.65	0.91	0.04
Slope-ET_o	1.08	0.81	0.95	0.06
RE-ET_o (%)	29.8	11.6	19.4	0.03

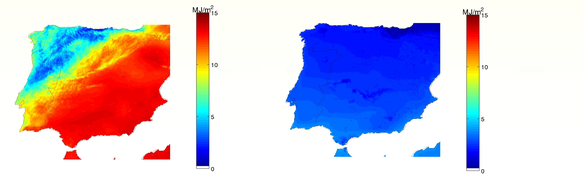

Figure 2. Example of a LANDSAF ET_o map (in MJ/m^2) covering Iberian Peninsula, August (left) and December (right), 2008

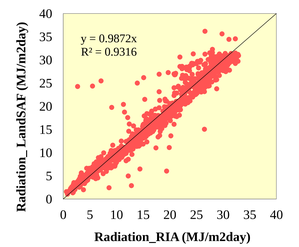

Figure. 3. Comparison between daily solar radiation measurements with PMFAO56 with the corresponding LandSAF values in Córdoba station during 2007-2009 period.

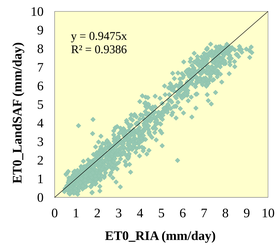

Figure. 4. ET_o estimated using PMFAO56 and the MAK-LandSAF method (new approach) in Córdoba station during 2007-2009 period.

CONCLUSIONS

This study has proved the LandSAF methodology as an excellent tool for the determination of reference ET (ET_o). Thus, ET_o determined using the new approach of Makkink was compared with the ET_o provided by a weather station network composed by 57 stations located throughout Andalusia, southern Spain, obtaining very satisfactory results. LandSAF methodology provides an accurate tool to estimate reference evapotranspiration from satellite data for areas where there are limited or non-existent conventional ground-based weather data. We applied the revised Makkin equation proposed by de Bruin et al. (2012), which does not underestimate ET_o anymore under arid conditions, in contrast to the original Makkink formula (Allen et al., 1998; Gavilán et al., 2008; Irmak et al., 2008). In a forthcoming paper (de Bruin et al., 2012) we will discuss the behavior of the new revised Makkink equation under arid and windy conditions. It will be shown that PMFAO56 is sensitive to errors when input data are used gathered over dry ground instead over well-watered refrence grass. Our novel approach is less sensitive to these errors.

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