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Validation of reference evapotranspiration from Meteosat Second Generation (MSG) observations

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ABSTRACT

This article presents validation results of the grass Reference Evapotranspiration (ET_o) product, which is provided operationally by the Satellite Applications Facility on Land Surface Analysis (LSA SAF). ET_o is considered to be the evapotranspiration from a hypothetical extensive well-watered field covered with green grass (12 cm high and with 0.23 albedo), under the given down-welling short-wave radiation. The LSA SAF product is estimated from daily solar radiation at the surface via a methodology designed to be applicable to that well-defined reference surface. In line with its definition, the LSA SAF ET_o product is based on estimates of the radiative energy available at the surface.

Validation of ET_o estimates is challenging, given the difficulties of finding reliable in situ measurements that meet the ET_o definition. We show that for the site that matches closely the reference surface (Cabauw, The Netherlands), the LSA SAF product outperforms other commonly used methodologies, even when these use in situ observations as input. However, observations taken at other stations, located in areas that do not deviate greatly from the reference surface, put into evidence the high uncertainty in local measurements. It is shown that the LSA SAF ET_o product follows well in situ values, with average differences of 0.3 mm/day or less for mid-latitude sites and of the order of 1 mm/day for the Spanish sites near Cordoba and Albacete. Local advection effects cannot be ignored in measurements performed in the latter stations, where summer conditions are mostly warm and dry. In situ ET_o measurements performed in those cases with lysimeters within limited fields are higher than satellite estimates due to advection of warm dry air from the vicinity, which acts as an extra source of energy. It is shown that this effect can be parameterized as a function of near surface air temperature. However, it is argued that those local advection effects should not occur in the idealized surface referred above.

In contrast to other ET_o estimates, the LSA SAF product is not influenced by local aridity or advection effects, and therefore it is particularly appropriate for large scale climate assessments, including drought monitoring (e.g. by considering the ratio of actual and reference evapotranspiration). Additionally, it provides suitable estimates of irrigation requirements in support of water management.

1. Introduction

Due to the rapid growth of the world population the demand for agricultural products, either for basic needs of life or for general well-being, is increasing rapidly. Agriculture is one of the main consumers of fresh water, whereas in many regions fresh water is scarce. There is a need for efficient water management in order to use the scarcely available water resources optimally. This implies that formal water legislation is needed leading to fair and effective use of available water resources. For this purpose, easily available information on crop water

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requirements, i.e. on optimum water consumption of crops, is needed. In the last decade, the concept of the so-called water footprint has been introduced which is defined as the total volume of freshwater used to produce a particular agricultural crop or product (Hoekstra and Hung, 2002), which in turn is directly related to crop evapotranspiration (ET_c) (Zhuo et al., 2014). This quantity is determined by many parameters, such as crop characteristics, weather conditions, water availability, soil properties, plant diseases, and management skill of the farmer. In order to provide guidelines for optimum water management, the Food and Agricultural Organization of the United Nations (FAO) have published a number of reports, namely Doorenbos and Pruitt (1977), and Allen et al. (1998; hereafter FAO56). These are based on the estimation of the so-called reference (crop) evapotranspiration (ET_o), i.e., the evapotranspiration (ET) from a hypothetical extensive well-watered green grass field, with clearly defined characteristics, under the given down-welling short-wave radiation. In the FAO56 report, ET_o is proposed to be estimated using the Penman-Monteith equation, together with the respective parameters also provided (i.e., those considered valid for the reference surface), and a number of guidelines for the measurement of the input variables; this methodology will be referred hereafter as PMFAO.

The basic idea behind the ET_o approach is that meteorological and crop factors are separated and that plants respond to the atmosphere's evaporative demand. As such, it is assumed that ET_o depends on meteorological factors only and that, once ET_o is estimated, it is possible to determine the ET for any specific crop and development stage, as long as the corresponding crop factor, K_c, is known (FAO56). The meteorological variables determining ET_o are: incoming solar radiation (global radiation), mean, minimum and maximum air temperature at 2 m (T_{air}), mean, minimum and maximum relative humidity of the air at 2 m, and wind speed at 2 m, as detailed in FAO56 (in particular Eqs. (4) to (39) therein). It is required that these meteorological variables are measured over a surface that resembles the reference for which ET_o is defined, i.e., over well-watered grass growing in 'extensive' fields. In practice, high quality meteorological stations where the required input weather parameters are measured over well-watered reference grass are almost non-existent, particularly in semi-arid regions. In remote regions, the density of weather station networks is sparse or they are in poor conditions, and in many developing countries weather stations over well-watered grass are not present. De Bruin et al (2016) showed that ET_o can be essentially estimated from solar radiation at the surface, since this variable controls net radiation over the reference surface. The proposed methodology is used by the Satellite Applications Facility on Land Surface Analysis (LSA SAF, Trigo et al., 2011) to routinely generate daily ET_o from solar radiation at the surface estimated from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board Meteosat Second Generation (MSG) (Geiger et al., 2008; Carrer et al., 2012). This article further discusses the advantages and caveats of this method through comparison between ET_o satellite-based estimations, ET_o estimations using PMFAO with in situ meteorological observations, and ET_o in situ measurements.

This article provides a brief description of the methodology used to derive the LSA SAF ET_o product (Fig.1) from SEVIRI/MSG observations in Section 2. The strategy and data used to assess the quality of this product is then presented in Section 3, followed by Section 4 where the validation results are described. These are globally analysed in Section 5, together with the relevant factors that impact local measurements and estimates of ET_o. Concluding remarks are presented in Section 6.

2. The LSA SAF reference evapotranspiration product

ET_o refers to the ET from a hypothetical extensive well-watered field covered with 12 cm high green grass, with an albedo of 0.23 and a fixed surface resistance of 70 s m^{-1}, under given down-welling short-wave radiation (FAO56). The reference surface closely resembles an extensive surface of green, well-watered grass of uniform height, actively growing and completely shading the ground. The fixed surface resistance of 70 s m^{-1} implies a moderately dry soil surface resulting from about a weekly irrigation frequency.

The crop ET under standard conditions, denoted as ET_c, is the ET from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. The amount of water required to compensate the ET loss from the cropped field is defined as crop water requirement. Although the values for crop ET and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop ET refers to the amount of water that is lost through ET. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application. ET_c can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach (Monteith, 1965). As there is still a considerable lack of information for different crops, the Penman-Monteith method is normally used for the estimation of the standard reference crop to determine its ET rate, i.e., ET_o, as recommended in FAO56. Experimentally determined ratios of ET_c / ET_o, called crop coefficients (K_c), are used to relate ET_c to ET_o (FAO56; Giménez et al., 2013).

The algorithm used by the LSA SAF to estimate ET_o (the so called DMETREF product described in ATBD_DMETREF, LSA SAF Team, 2016) assumes that the air above the reference (well-watered) surface is close to saturation, being valid the following approximation (De Bruin et al., 2016):

$$ET_o = \frac{1}{\lambda}\left[\frac{\Delta}{\Delta + \gamma} Q^* + \beta\right] \quad (1)$$

where λ is the latent heat of vaporization, Δ is the slope of saturation water vapour pressure versus temperature, γ is the psychometric constant, Q^* is the net radiation (Rnet) at the surface and β a constant (20 Wm^{-2}) which has been introduced to compensate the deviation of near surface conditions from fully saturated air. This might be explained by entrainment of relatively warm and dry air present aloft into the well-mixed atmospheric boundary layer during daytime. As such, the relative humidity in the lower boundary layer is less than 100%, despite the high surface evaporation rate. As for the daily Rnet, Q^*, it has been noted that over a well-watered surface with an albedo of 0.23 (such as the reference conditions) we have:

$$Q^* = (1-0.23)K^{\downarrow} - C_S\frac{K^{\downarrow}}{K^{\downarrow}_{ext}} \quad (2)$$

where $K^{\downarrow}$ is the daily downwelling short-wave radiation at the surface, $K^{\downarrow}_{ext}$ is the downwelling shortwave radiation constant at the top of the atmosphere, and C_S an empirical constant (110 Wm^{-2}). Eq. (2), denoted hereafter Slob - de Bruin, was adjusted using data from Cabauw in The Netherlands, representing observations over a field very similar to the reference surface (de Bruin, 1987; De Bruin and Stricker, 2000, De Bruin et al., 2016). The LSA SAF ET_o product is estimated using Eq. (1) and Rnet based on Eq. (2), where $K^{\downarrow}$ is routinely derived by the LSA SAF from SEVIRI/MSG data (e.g., Geiger et al., 2008; Trigo et al., 2011; Carrer et al., 2012).

The LSA SAF ET_o product is generated daily for the whole SEVIRI/MSG disk (Fig.1). It is meant to present an estimate of reference crop ET as defined above. The concept of reference crop ET is that it is defined for a reference surface grass growing in an extensive field, although practical application of FAO guidelines partly disregards this definition. In one interpretation, the adjective 'extensive' implies that field-edge effects can be neglected. But this contradicts the way the reference crop ET concept is applied to cases where limited-area fields are considered, and therefore edge effects are included. This concerns the question