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Article

Crop Water Requirements on Regional Level using Remote Sensing Data – A Case Study in the Marchfeld Region

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Keywords: irrigation, crop water requirements, evapotranspiration, satellite image, remote sensing, DEIMOS-1

Summary: This research presents an operative application of satellite–based technologies to estimate crop water requirements (CWR) on regional level. The study is located in the agricultural area of Marchfeld (Lower Austria) and focuses on the year 2012. Agricultural production in this region requires irrigation which draws its resources from the groundwater. Due to its impact on hydrology and environment this practice necessitates close monitoring and management. In this process the CWR is an important piece of information, which can be derived from satellite data. We used multi-temporal (6 acquisitions, with an average revisit time of 16 days) and multi-spectral (visible and near-infrared) imagery of the DEIMOS-1 satellite sensor data in combination with local agro-meteorological measurements. In a first step, the leaf area index (LAI) and albedo maps were derived from atmospherically corrected satellite data. Those were used to generate maps of potential evapotranspiration (ET_p) by direct application of the Penman-Monteith equation. Then, we produced a crop mask of the areas potentially irrigated. This was achieved by using an unsupervised image classification approach in combination with a post-classification analysis of the time-series of the crop development. Rain gauges data from a number of weather stations were spatially interpolated to produce a map of precipitation (P). Finally, the crop water requirements were calculated as the difference between ET_p and the precipitation and aggregated over 10-day interval periods. Reference evapotranspiration (ET_o) for the growing period resulted in 391 mm. The extent of irrigated crops covered an area of 21,278 ha with a maximum ET_p of 5.6 mm/day at the end of June. The total crop water requirement resulted in 34.26 million m³ for the year 2012.

Zusammenfassung: *Berechnung des Pflanzenwasserbedarfs für Sommerfeldfrüchte mittels Fernerkundungsdaten. Eine Fallstudie in der Marchfeld-Region.* Diese Arbeit präsentiert eine Berechnung des Pflanzenwasserbedarfes auf regionaler Ebene. Die Studie wird innerhalb der landwirtschaftlichen Region Marchfeld (Österreich) für das Jahr 2012 durchgeführt. Die landwirtschaftliche Produktion dieser Region ist definiert durch Feldbewässerung, die ihre Ressourcen aus dem Grundwasser bezieht. Der Einfluss auf die hydrologischen- und Umweltbedingungen macht eine genaue Beobachtung dieser Anwendung unumgänglich. Der Pflanzenwasserbedarf ist dabei eine wichtige Information, sowohl für die Beobachtung als auch für operationelle Entscheidungen. Die Analyse basiert auf multi-temporalen (6 Bildaufnahmen, 16 Tage Wiederholzyklus), multispektralen (sichtbares Licht und nahes Infrarot) Satellitenbildaufnahmen des DEIMOS-1 Sensors und lokalen agro-meteorologischen Daten. Zuerst wurde der Blattflächenindex (Leaf Area Index – LAI) und die Albedo aus den atmosphärisch korrigierten Satellitenbildern berechnet. Mit diesen Daten wurden durch eine direkte Anwendung der Penman-Monteith Gleichung Karten der potentiellen Evapotranspiration erstellt. Mit einer unüberwachten Klassifikation der zeitlichen Pflanzenentwicklung und einer nachfolgenden Analyse wurde die räumliche Verteilung von Sommerfeldfrüchten ermittelt. Weiters wurden Niederschlagsdaten von elf Wetterstationen interpoliert, um eine räumliche Abschätzung der Niederschlagsverteilung zu erhalten. Zuletzt wurde der Wasserbedarf der Sommerfeldfrüchte als Differenz der potentiellen Evapotranspiration und des Niederschlages berechnet und in 10-Tages-Intervallen aggregiert. Das Untersuchungsgebiet wies während der Vegetationsperiode eine totale ET_0 von 391 mm auf. Die Produktion von Sommerfeldfrüchten nahm eine Fläche von 21.278 ha in Anspruch und erreichte eine maximale ET_p von 5,6 mm/Tag. Der gesamte Pflanzenwasserbedarf für Sommerfeldfrüchte innerhalb der Marchfeld-Region im Jahr 2012 war 34,26 Mio. m³.

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1 Introduction

Irrigated agricultural land has a high productive capacity producing between 30% to 50% of the world food crop on 17% of all arable land (Seckler et al. 1999). Efficient management of water resources is of particular importance considering that 70% of global freshwater withdraws are done by agriculture. The last decades have seen a growth in use of water for irrigation, which is predicted to further increase (Collins et al. 2009). Adjacent to nutrient management, efficient water management is considered to be the main component that can contribute to production increases (45% to 70% for most crops) thus providing future food security in a sustainable way (Mueller et al. 2012).

The need for irrigation arises when precipitation does not compensate the water loss caused by evapotranspiration (ET) of the plant surface. Usually, farmers and irrigation managers will aim to meet crop water requirement (CWR), defined as the deficit between ET loss and precipitation, by applying irrigation to achieve optimal crop development and yield (Allen et al. 1998). Water is taken from available sources, e.g. rivers and groundwater, and extensive infrastructure, such as canals, damns, water reservoirs, pumps, is needed to make water accessible for irrigation. An example is the Marchfeld region in Austria where irrigation is deployed since the 1970s. Between the years 1986 and 2004 the "Marchfeldkanal-Projekt" was realized in response to dropping groundwater levels. This canal system diverts water from the Danube River and conveys it to the Marchfeld region to make it accessible for irrigation practice. The method can result in considerable effects on the surrounding environment like biodiversity losses due to lowered groundwater tables or pollution of rivers by agricultural inputs (David et al. 2000). Further problems are limited water supply for downstream users, soil erosion and nutrient elution (Shanan 1987, David et al. 2000). In the Marchfeld the main issues are the regulation of groundwater levels and the dilution of nitrate into the groundwater. These problems deserve special recognition since the resources are also used as industrial, domestic and drinking water.

In the Marchfeld region the withdrawal of water for irrigation is currently approximated by measurements of the groundwater level. Field to catchment scale estimates of water requirements are important in the assessment of regional water consumption and groundwater depletion and could help to improve estimates of irrigation withdrawal. This information can be used to coordinate allocation of resources in irrigation, like volumes of water and investments in infrastructure, and in the compilation of water management plans to achieve an increased efficiency in the water use (Pereira et al. 2002).

Crop development is one of the driving factors determining water needs and it highly depends on spatial and temporal factors. A temporal variation is a result of vegetation dynamics over the growing season. Spatial variation is related to climatic conditions on large scale, and on smaller scale related to other factors like soil type and fertility, crop variety and management. Estimations of water requirements based on regional statistics, static crop maps and standard crop coefficients are not capable of accounting for this variability (Frenken & Gillet 2012). Therefore, precise estimations of water requirements need to take into account spatial and temporal information on the actual development of crops.

Crop development can be monitored using multi-spectral and multi-temporal observations from satellite platforms (Ozdogan et al. 2010). Current platforms are acquiring multispectral imagery in a spatial resolution precise enough for analysis of agricultural vegetation with suitable revisit intervals. For instance, the commercial Spanish satellite of the DMC (disaster monitoring constellation) DEIMOS-1 provides data in 3 spectral bands with a ground sampling distance (GSD) of 22 m and 2 – 3 days revisit time (Deimos-Imaging 2014). The freely available Landsat-8 satellite featuring 8 spectral bands provides 16 days revisit time and a GSD of 30 m. Sentinel-2, an upcoming European Space Agency (ESA) mission, will provide 13 spectral bands with a resolution of up to 10 m in a revisit interval of 2 – 3 days. These satellite sensors offer the possibility to monitor large crop areas in intervals (7 – 10 days) suitable for the calculation of CWR in a variety of agricultural conditions.

Other possible applications of EO data in agriculture are the implementation in crop models (CASA et al. 2012), monitoring of the nitrogen status (SCHARF et al. 2002) and to predict yields (JÉGO et al. 2012).

This paper focuses on the calculation of ET_p and an estimation of the seasonal crop water requirements in the area of Marchfeld, an important agricultural region located in Lower Austria, where irrigation is regularly applied during summer months. Our approach combines daily agro-meteorological data from local stations and the processing of multi-spectral images based on the methodology described by D'URSO et al. (2001, 2010) using the Penman-Monteith approach (ALLEN et al. 1998). We used rain gauges data from eleven weather stations located in the region and 6 images with a spatial resolution of 22 m acquired with an average revisit time of 16 days. We performed an image classification using the satellite-based crop development curves as input feature to differentiate different types of crops. This was done to identify areas used for production of summer crops, which are most likely to be irrigated during the time of interest.

The paper presents the results of a case study and discusses the findings in the context of operative tools to support irrigation water management at regional scale.

2 Material

2.1 *Study Area*

Marchfeld is located in Lower Austria, north east of Vienna (Fig. 1). The average annual precipitation is 500 mm – 550 mm making it the driest region of Austria. Annual precipitation during the vegetation period (April – September) is 200 mm – 440 mm. Dry periods (time with no daily precipitation higher than 5 mm) of three weeks can occur averagely 5 times per year, longer dry periods of 30 – 34 days are a yearly occurrence (NEUDORFER 2002). Modelling of future climatic development for Marchfeld and its surrounding regions suggests a decrease of precipitation volumes and an expected increase of likelihood for drought events (PAL 2004, DUBROVSKY et al. 2008, EITZINGER et al. 2009, TRNKA et al. 2009). The high average wind speed of about 3.5 m/s has an amplifying effect of the dry climate considering plant transpiration. The agricultural area has an extent of 60,000 ha of arable land of which more than 21,000 ha are regularly irrigated each year. The soil consists mainly of fertile aeolian slit deposit which, together with the pannonian climate, high solar radiation and flat terrain forms a well-qualified region for agricultural production. The main crops cultivated in summer are vegetables (11% of the crop area), sugarbeet (10%) and potatoes (7%). Cereal crop types are cultivated on about two-thirds of the crop area. Limitations to agricultural production are low precipitation and a predominantly low field water capacity of 70 mm and less. This means that the soil can hold only a low amount of water thus limiting availability to plants in dry periods.

Although Marchfeld is one of the driest regions in the country, it is still one of the primary producers of agricultural goods in Austria. This is possible due to the use of irrigation that is used to compensate scarce precipitation. The infrastructure of the "Marchfeldkanal Projekt" consists of 100 km of canal and 8 weirs which control surface water flow and height. To control groundwater levels 22 pumping stations and 7 infiltration basins were implemented. The cost of construction was 207.8 million Euro (NEUDORFER & WEYERMAYER 2007). Water for application on field is pumped from the groundwater through wells. In this case decentralized, mobile pumps are run on diesel or less often by electricity. In some cases centralized pumping stations provide pressurized water via a distribution network. The majority of crops are irrigated from May until end of September. The only crop regularly irrigated afterwards (until mid-October) is spinach.

2.2 *Satellite Data*

In this study, we used satellite images acquired by DEIMOS-1, a satellite of the DMC (disaster monitoring constellation). DEIMOS-1 features a multi-spectral sensor providing 22 m resolution in 3 bands (NIR: 0.77 µm –

0.90 µm, Red: 0.63 µm – 0.69 µm, Green: 0.52 µm – 0.60 µm) with a revisit interval of 2 – 3 days. DEIMOS-1 was chosen because it offers a cost-effective solution to monitor crop development with suitable temporal, spatial and spectral resolution to work at field and district scales. Imagery was acquired on six different dates in 2012 to cover the growing season: June 17th, July 30th, August 1st and 20th, September 5th and 18th.

The imagery was provided orthorectified to a sub-pixel accuracy of about 10 m. The correction was performed by the data supplier using ground control points and the shuttle radar topography mission (SRTM v3) data as digital elevation model. An atmospheric correction using ATCOR (Richter 1998) was performed by the authors before further processing.

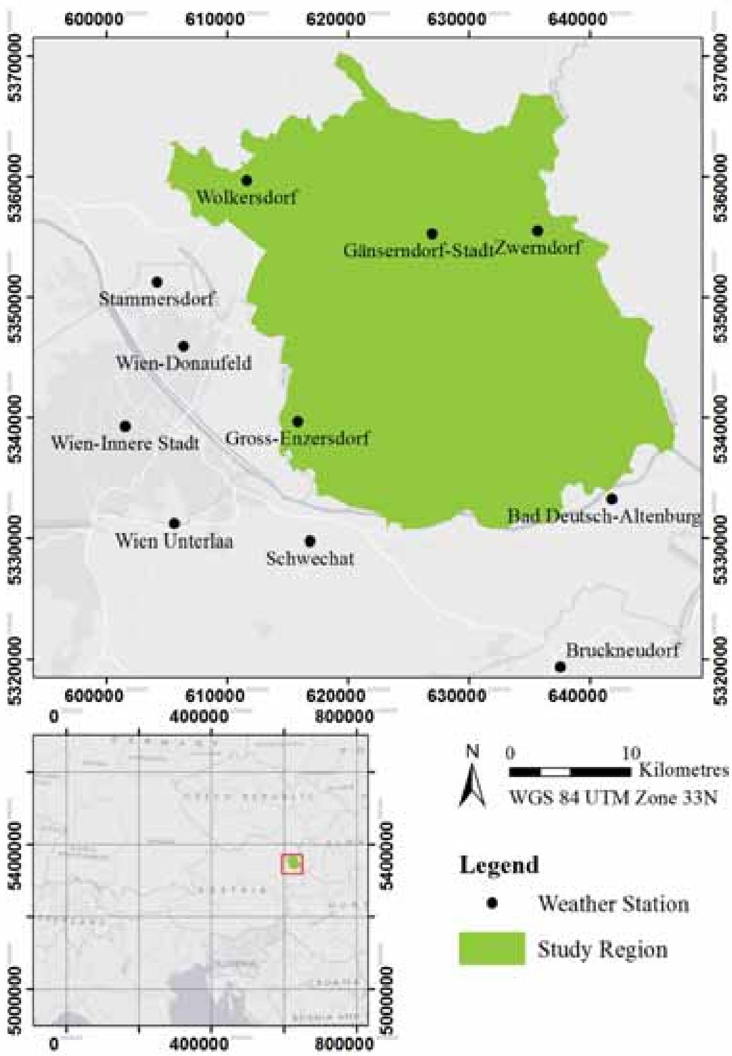

Fig. 1: Study area of Marchfeld (Lower Austria) and location of the weather stations used for the spatial interpolation of precipitation.

2.3 *Agro-Meteorological Data*

Precipitation was recorded at eleven weather stations in the region (Fig. 1). Fig. 2 reports the mean cumulated precipitation volumes of all eleven stations and the data for the stations which recorded the seasonal minimum (148 mm at Zwerndorf) and maximum (249 mm at Wien-Unterlaa) values. For the calculation of the reference evapotranspiration (ET_0), we considered solar radiation, air temperature, windspeed and air humidity recorded at the Zwerndorf station only.

3 Methods

3.1 *Calculation of Crop Water Requirements*

Crop water requirements are defined as the potential evapotranspiration (ET_p) of a cropped surface area, net of the precipitation (P):

$$CWR = ET_p - P \tag{1}$$

Precipitation (P) can be measured from local weather stations. A critical factor in the precise estimation of CWR is the potential evapotranspiration of crops. A review of different procedures for the determination of ET is given by Courault et al. (2005) and Verstraeten et al. (2008). The approach for mapping ET used in this study is based on the methodology proposed by D'Urso et al. (2001, 2010) using the FAO-56 Penman-Monteith equation (Allen et al. 1998). It consists of two main components. First we estimate the reference evapotranspiration (ET_0) based on the FAO-56 standards. ET_0 indicates the amount of water removed from a standard vegetation surface (grass) through the process of evapotranspiration. In this case, ET_0 is a function of meteorological factors (solar radiation, wind speed, temperature, air humidity), which can be measured by local weather stations, and crop specific factors (LAI, albedo and crop height – h_c), which are kept constant in relation to the theoretical reference surface (LAI = 2.88, albedo = 0.23, h_c = 0.12 m).

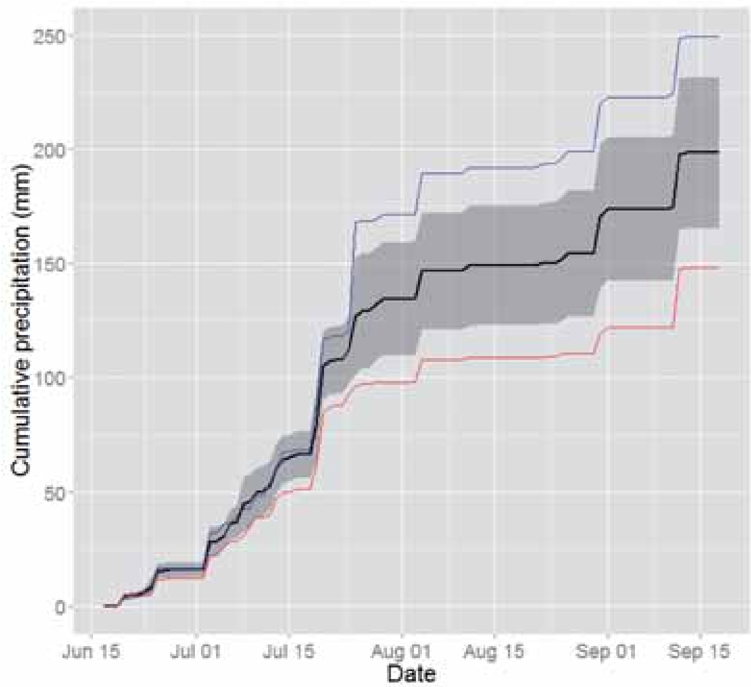

Fig. 2: Cumulated precipitation. The black line represents the mean value from all eleven weather stations, the shaded area is the standard deviation. Wien-Unterlaa recorded the total maximum of precipitation volumes (249 mm), Zwerndorf the minimum (148 mm).

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1+0.34)u_2} \quad (2)$$

R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}],
G = soil heat flux density [MJ m^{-2} day^{-1}],
T = mean daily air temperature at 2 m height [°C],
u_2 = wind speed at 2m height [m s^{-1}],
e_s = saturation vapour pressure [kPa],
e_a = actual vapour pressure [kPa],
e_s–e_a = vapour pressure deficit [kPa],
Δ = slope vapour pressure curve [kPa °C^{-1}],
γ = psychrometric constant [kPa °C^{-1}].

Subsequently the crop coefficient (K_c) is calculated. K_c is defined as:

$$K_c = \frac{ET_p}{ET_0} \quad (3)$$

Traditionally, i.e. in non-satellite-based approaches, K_c is calculated from measurements of actual evapotranspiration and contemporaneous ET_0 estimates. This way K_c has been calculated for different conditions and is reported in tables for several crops. Tabulated data represents a fixed value suitable for comparing crop types under general conditions. Because crop development is subject to change in regard to management and environmental factors, the K_c value should be dynamically adjusted to the actual conditions in order to achieve precise estimation of water requirement on field and regional scale.

In this study, we used the approach proposed by D'Urso et al. (2001, 2010) to estimate ET_p, where crop parameters used in the FAO-56 Penman-Monteith equation are replaced by LAI and albedo maps. LAI was calculated from the weighted difference vegetation index (WDVI) using the CLAIR model (Clevers 1989). A site specific model was calibrated and the satellite-based estimation of LAI was validated using ground measurements. The calibration procedure and results are presented in Vuolo et al. (2013). The surface albedo is substituted by the wavelength-integrated ground reflectance where wavelength gap regions are supplemented with interpolation (Richter & Schläpfer 2014). This calculation was performed using ATCOR module implemented in ERDAS Imagine. Crop height (h_c), which controls the resistance in canopy aerodynamic properties, was set to a constant value of 0.3 m, representing an average height for crops in the region. This was done because measurements of crop heights are not feasible for large areas over a time period of several months and a fixed value is considered to be a satisfactory compromise for the estimation of ET_p (D'Urso & Calera Belmonte 2006).

To produce daily estimates of ET_p, K_c maps were derived for each acquisition date (according to (2)) and they were temporally interpolated to obtain daily K_c values from June 17th to September 18th. For this purpose, we used the "Whittaker Smoother" (Whittaker 1922, Eilers 2003, Atkinson et al. 2012). The smoothing parameter (λ) was set to 15. Subsequently, a daily estimation of ET_p was performed by multiplying daily K_c with corresponding daily ET_0 estimates. In a final step the total water requirements were aggregated in 10-day time steps.

3.2 *Spatial Interpolation of Precipitation*

To derive the variability of precipitation events over the region of interest, rain gauges data were spatially interpolated on a daily basis using the inverse distance weighted (IDW) method. IDW interpolation is a well performing method for interpolating precipitation and less complex to apply than the similar performing regression-kriging method (Wagner et al. 2012). The IDW algorithm was applied in MATLAB using a code provided by Fatichi (2012). The interpolation was set to take into account the 3 nearest neighbours of each point of measurements to produce a 22 m × 22 m grid corresponding to the K_c raster dataset.

3.3 *Crop Category Classification*

The aim of the crop category classification was to identify the crop areas that are potentially irrigated. For this purpose, we defined two crop categories (summer and winter crops) and used the summer crop areas to compute the total water requirements. The K_c estimation from the satellite time series provided a quantification of the crop development over time which was used as an input feature in the image classification. In our case, the time series starting on June 17th covered the development of winter crops in their late or senescence stages. Likewise summer crops were recorded during their full development stage.

In a first step, non-agricultural areas such as urban, forest and water were identified using CORINE land cover (CLC) with a pixel size of 100 m (European Environment Agency 2006) and were removed from the K_c dataset.

In a second step, an unsupervised image classification of the time series with an initial number of 12 clusters was performed. The 12 clusters were then aggregated to summer and winter crop classes based on a visual interpretation of the temporal crop coefficient development of each cluster. We introduced a third class (namely secondary crop) to account for double cropping systems, i.e. two or more crops in the same field during a single growing season.

4 Results

First we present the results of the summer crop area classification. This is followed by the results of analysis of the agro-meteorological data. The CWR is presented at the end of this section. ET_p and CWR estimates were calculated considering summer crops only, because of the overlap between their development and the irrigation season. These were calculated on a daily basis and temporally aggregated to 10-day intervals. For ease of discussion, the considered reference period from June 17th to September 18th 2012 is referred to as the "growing season".

4.1 *Crop Area Estimation*

Results of the multi-temporal classification indicated that the total area used for crop production in Marchfeld was 60,691 ha. Summer crop cultivation accounted for 35% (21,278 ha) of the total crop area. Cultivation of secondary and winter crops accounted for 17,149 ha and 22,248 ha, respectively. An accuracy assessment of the crop map was performed using 140 random sampling points, which were visually interpreted using the crop development and colour composites. The class "summer crop" reached an accuracy of 90.5%. An error matrix for this class is given in Tab. 1.

The crop areas and the intensity of land use for summer crops were further analyzed based on the boundaries of administrative districts (Fig. 3). The region Andlersdorf dedicated most of its area to summer crop production (43% of the district area, 231 ha). The minimum of 5% (61 ha) was situated in Strasshof, a district consisting mainly of urban areas. The district of Groß-Enzersdorf had the largest total area of summer crop production with 2,245 ha (29% of the district area). The percentage of land use for summer crop cultivation within Marchfeld for each administrative district is given in Tab. 2.

4.2 *Analysis of Agro-Meteorological Data*

The average daily temperature recorded at Zwerndorf weather station ranged from 12.6 °C to 29.8 °C during the growing season.

Tab. 1: Error matrix of the crop mask classification.

		Reference data		
		Summer	**Other**	**User's accuracy**
Classification result	**Summer**	38	4	90.5 %
	Other	4	101	96.2 %
	Producer's accuracy	90.5 %	96.2 %	
		Overall accuracy	94.6 %	

Tab. 2: Percentages of summer crop area to district area.

Municipality	Area of summer crop cultivation (%)
Aderklaa	27.2
Andlersdorf	43.1
Angern an der March	16.1
Auersthal	21.8
Bockfließ	19.2
Deutsch-Wagram	20.5
Eckartsau	23.0
Engelhartstetten	27.3
Gänserndorf	21.5
Glinzendorf	37.6
Großebersdorf	24.5
Groß-Engersdorf	30.3
Groß-Enzersdorf	29.4
Großhofen	29.0
Groß-Schweinbarth	12.8
Haringsee	33.3
Lassee	28.3
Leopoldsdorf im Marchfelde	33.4
Mannsdorf an der Donau	31.5
Marchegg	28.5
Markgrafneusiedl	15.0
Matzen-Raggendorf	12.9
Obersiebenbrunn	35.2
Orth an der Donau	22.9
Parbasdorf	36.7
Pillichsdorf	25.8
Prottes	16.5
Raasdorf	23.1
Schönkirchen-Reyersdorf	21.9
Strasshof an der Nordbahn	5.7
Untersiebenbrunn	25.6
Weiden an der March	23.7
Weikendorf	24.0
Wolkersdorf im Weinviertel	16.0

The average wind speed at 2 m height was 2.7 m/s ($\sigma = \pm$ 0.8 m/s).

The reference ET reached a maximum value of 6.1 mm/day at the end of June. The minimum of 3.2 mm/day occurred at the beginning of September. The total ET_0 over the growing season was 391 mm (94 days). Fig. 3 reports the weekly averages of ET_0 in 2012 in relation to the averages of the years 2009 to 2011.

From the eleven stations, the highest amount of precipitation during the growing season was recorded in Wien-Unterlaa with 249 mm. The lowest volume was 148 mm at Zwerndorf. The interpolated measures of precipitations were aggregated to 10-day intervals and are presented in Tab. 3. Records of precipitation showed an expected eastward downtrend. Stations in the eastern part of the study area, i.e. Gänserndorf, Zwerndorf, Bad Deutsch-Altenburg and Bruck-Neudorf, recorded lower amounts of precipitation with a mean (μ) of 163 mm and a standard deviation (σ) of $\pm$ 16 mm compared to stations in the western part (μ = 222 mm and $\sigma = \pm$ 16 mm). A comparison of average weekly values between 2012 and the years from 2009 to 2011 is given in Fig. 4.

4.3 *Crop Water Requirements*

The maximum water requirements for the growing season considering a timeframe of 94 days resulted in 34.26 million m^3, which corresponds to an average requirement of 3.8 million m^3 per 10-days ($\sigma = \pm$ 4.4 million m^3). The aggregation to 10-day intervals presented a maximum water requirement of 7.9 million m^3 in mid-August. Precipitation exceeded potential evapotranspiration during two of the 10-day periods. In this case, the surplus of water resulted in 4.7 million m^3 and 0.6 million m^3 at the end of July and in mid-September, respectively.

Water requirements per district

The satellite-based calculation of water requirements was spatially aggregated to district level and normalized to the extent of the summer crop area per district to represent the spatial distribution of CWR. On average, the seasonal water requirement per district

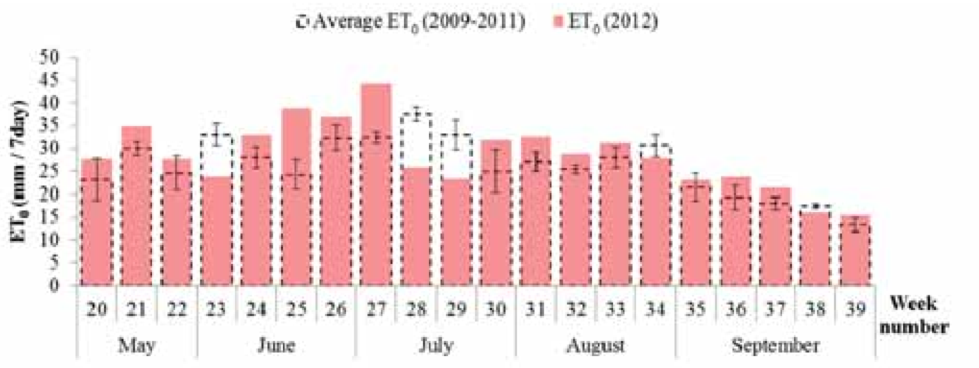

Fig. 3: Comparison between year 2012 and the average values measured in the last three years (2009 – 2011) for ET_0. The error bars indicate the standard deviation (1 time) within the four years (Zwerndorf).

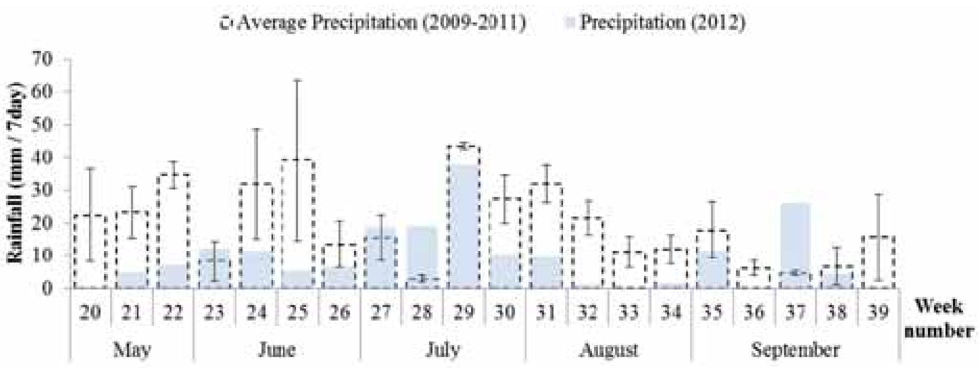

Fig. 4: Comparison between year 2012 and the average values measured in the last three years (2009 – 2011) for total rainfall. The error bars indicate the standard deviation (1 time) within the four years (Zwerndorf).

Tab. 3: Calculated values of reference evapotranspiration (ET_0), potential evapotranspiration of summer crops (ET_p), precipitation data and water requirements for the year 2012 from 17th of June to 18th of September; dates in the first column indicate starting points for 10-day intervals. Mean values (μ) and standard deviations (σ) refer to the spatial variation within the region of interest.

	ET_0 (mm)	ET_p (mm)		Precipitation (mm)		Water requirements of summer crops (million m^3)
		μ	σ	μ	σ	
June 17th	52.1	50.6	8.9	14.6	2.8	7.66
June 28th	61.4	56.0	13.6	19.4	5.0	7.87
July 9th	41.8	36.8	9.4	30.5	5.9	1.38
July 20th	36.6	32.0	7.7	55.0	14.1	-4.77
July 31st	47.7	42.8	10.0	13.4	4.8	6.08
Aug. 11th	42.9	39.8	10.1	2.3	1.2	7.95
Aug. 21st	43.1	38.4	11.5	2.1	1.2	7.75
Sep. 1st	32.2	23.7	9.2	19.0	4.5	0.98
Sep. 11th	33.2	20.4	9.9	24.0	2.2	-0.64
Overall	391					34.26

resulted in 1,523 m³/ha (σ = ± 288.4 m³/ha). The maximum CWR was observed in the district of Weiden an der March with a CWR of 1943 m³/ha. The minimum CWR of 968 m³/ha was observed in Pillichsdorf. Fig. 5 shows the spatial distribution of CWR.

5 Discussion and Conclusion

This study described an application of satellite-based technologies combined with agrometeorological data and spatial modelling to estimate water requirements during the irrigation period in the agricultural region of Marchfeld (Austria) for the year 2012. Reference evapotranspiration was calculated using the FAO-56 Penman-Monteith equation (Allen et al. 1998) and meteorological data recorded on-site. For a spatial estimation of precipitation events data from eleven rain gauges in the region of interest were interpolated. A time series of DEIMOS-1 imagery was acquired to follow the crop development during the growing season. Derived LAI and albedo maps were used to calculate the crop coefficient maps based on an approach proposed by D'Urso et al. (2001, 2010). The crop co-

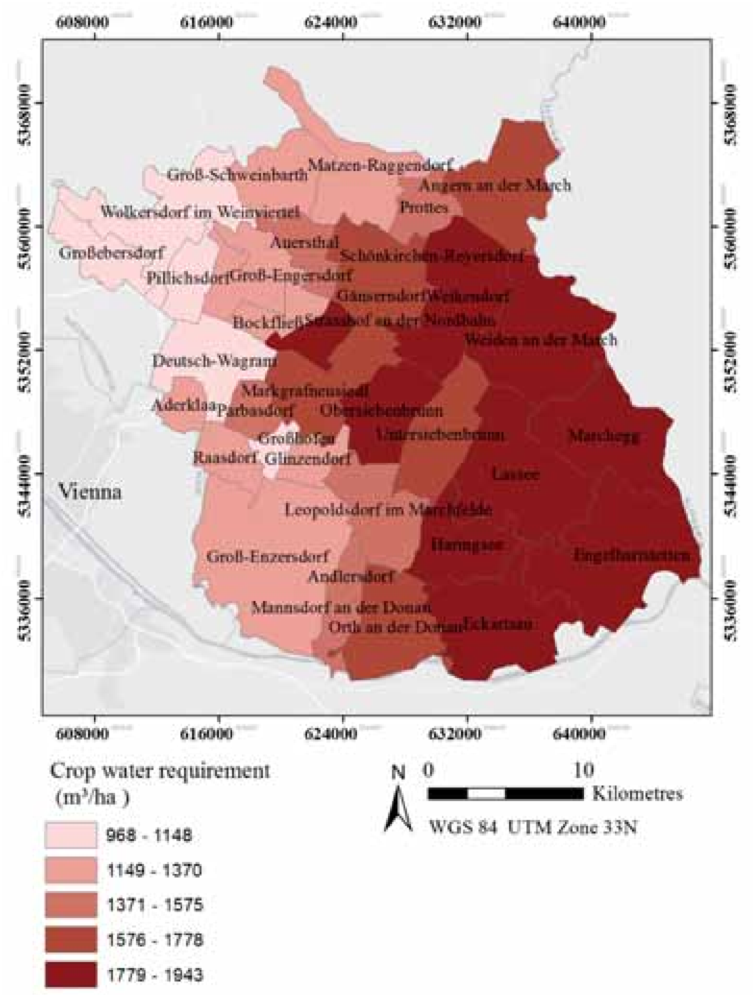

Fig. 5: Crop water requirements (m³/ha) of summer crops per district in Marchfeld for the growing season 2012.

efficient maps were temporally interpolated to derive daily estimations of crop development. Subsequently reference evapotranspiration and satellite-based K_c data were used to calculate potential evapotranspiration on a pixel-basis. The satellite time series was further used to classify the agricultural surface in winter or summer crops. The land cover map and the pixel-based potential evapotranspiration were used to calculate the total water requirements of summer crops.

Results indicated that the total area extent of summer crop production in the year 2012 was 21,278 ha with a total potential evapotranspiration of 340 mm. The total precipitation for the observed time period was 180 mm calculated as the average within the study area resulting in total water requirements for summer crops of 34.26 million m^3 (in 94 days; 368,429 m^3/day on average). This represents the maximum level of water needs in the region for the year 2012.

Contemporaneous measurements of the actual water withdraws were not available for the same reference period. A coarse comparison is only possible considering the aggregated data per season and the estimations of groundwater withdrawal from the "Marchfeldkanal Betriebsgesellschaft", the company responsible for the canal infrastructure. The estimation is based on measurements of the fluctuations of groundwater levels for representative measurements points. The Marchfeldkanal Company estimates the withdrawal for irrigation purposes by limiting the time frame to summer periods where distinct drops in the groundwater levels can be observed. The timeframe of the measurements varies between 55 days (1995) and 162 days (2012). The resulting estimation for agricultural irrigation for the years from 1991 to 2008 ranges between 7.5 million m^3 (year 2005) and 45.1 million m^3 (year 2000). For the year 2012, the estimation of water withdrawal was 35 million m^3 considering a timeframe of 162 days starting at the end of April (Neudorfer 2013).

For the Marchfeld region water regulation is a major management and resource issue which is closely monitored at groundwater level (Neudorfer & Weyermayer 2007). Knowledge of the regional water requirement and its spatial and temporal distribution provide an important base for further decision making processes. Closer examination of the water deficit at field level can help to develop a more precise framework for the implementation and regulation of water management practices. Current assessments of this variable in the Marchfeld region are based on local point measurements and are thus fixed to small scale calculations (Cepuder & Nolz 2007).

In his publication about "Accounting for Water Use and Productivity" Molden (2006) identifies three levels of water use: "[…] a use level such as an irrigated field or household, a service level such as an irrigation or water supply system, and a water basin level that may include several uses". *EO* data can help to bridge the gaps between these levels since water deficits can be assessed in detail on large scale in relatively short time steps.

Estimations of regional water requirements similar to the presented research were performed in a recent study by Akdim et al. (2014) for the Doukkala area in western Morocco. In addition to the regional calculation of water deficit this publication further surveys the water withdrawal for irrigation by measurements at central pumps. In doing so, the authors identified times of water deficits, the applied irrigation and the occurrence of mismatches between the two. For Marchfeld the volume of water withdrawal for irrigation on regional level is difficult to obtain due to the decentralized network of pumping stations, their individual management and data privacy issues. Similar to the study of Akdim et al. (2014) it would allow quantifying the adequacy of water allocation in certain times or areas, an important topic worldwide as emphasized by Wallace (2000). The estimation of regional water deficit in Marchfeld is a first step towards this direction. The lack of comparable data emphasizes the need for expanded research activities on this topic.

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