European Commission

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ASAP Water Satisfaction Index

Technical Manual of WSI version 1.1

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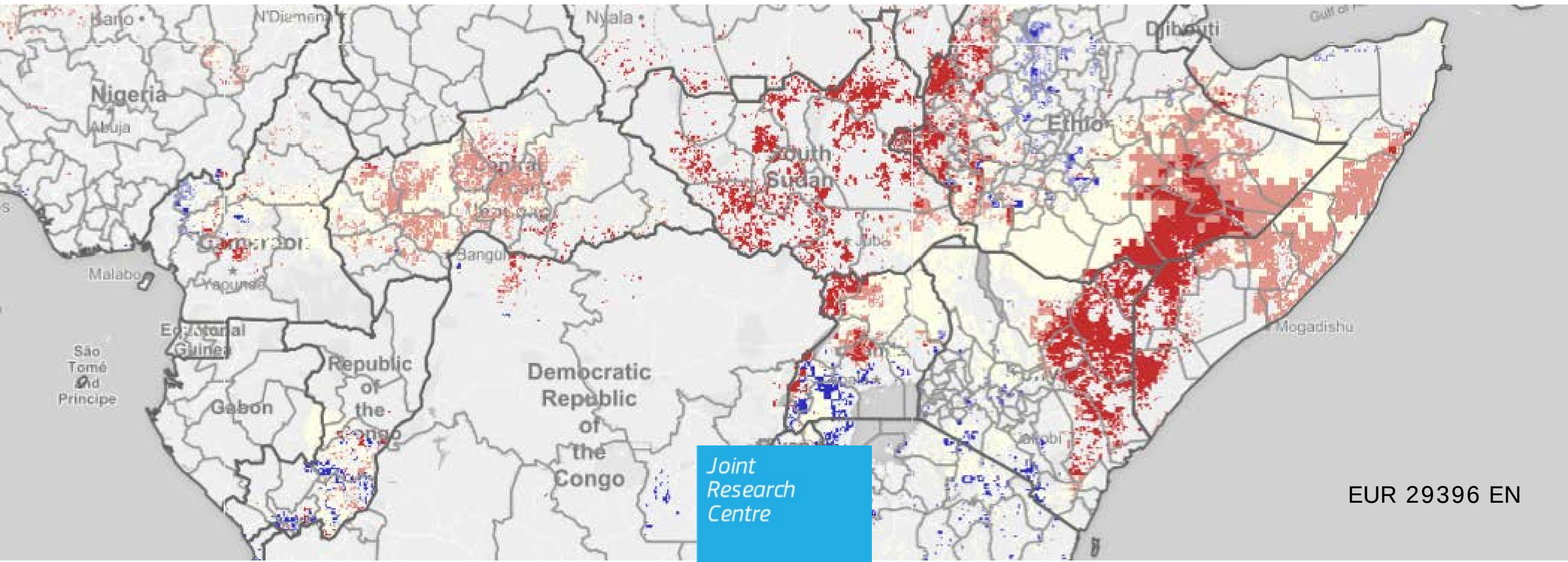
2018



Joint Research Centre

EUR 29396 EN

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JRC113061

EUR 29396 EN

PDF ISBN 978-92-79-96678-1 ISSN 1831-9424 doi:10.2760/478822

Luxembourg: Publications Office of the European Union, 2018

How to cite this report: *Boogaard, H., Van Der Wijngaart, R., Van Kraalingen, D., Meroni, M. and Rembold, F., ASAP Water Satisfaction Index*, EUR 29396 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-96678-1, doi:10.2760/478822, JRC113061.

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Acknowledgements

Henk van der Ham (Wageningen University & Research) worked on the Oracle environment and refined the WSI database structure to improve performance of set up actions. Jan Clement (Wageningen University & Research) worked on the weighted Kc coefficients.

Abstract

This technical report describes the Water Satisfaction Index model that used in the ASAP (Anomaly hotSpots of Agricultural Production) early warning system.

1 Introduction

ASAP (Anomaly hotSpots of Agricultural Production) is a global early warning system being to trigger warnings about agricultural / rangeland production based on anomalies of three indicators, currently SPI1, SPI3 and NDVI.

ASAP works at GAUL1 level, focuses on arable land and rangelands through appropriate masks, and analyses anomalies only during the average growing season. The average growing season is retrieved at the pixel level using a simple phenology algorithm applied to MODIS NDVI profiles. The ASAP web GIS can be found at https://mars.jrc.ec.europa.eu/asap/map.php while a technical description of the system is available at https://mars.jrc.ec.europa.eu/asap/asap-info.php.

The Water Satisfaction Index (WSI) is an indicator of crop (or rangeland) performances based on the availability of water to the crop during the growing season. It uses a rainfall and evapotranspiration driven water balance accounting scheme to estimate water available to the plant.

The WSI has been developed to replace the SPI3 in ASAP. This is expected to improve the performance of the system as well as improving its sensitivity for agricultural drought as compared to meteorological drought.

This technical report describe the WSI and its functioning within ASAP.

2 Data

The global WSI uses both static layers (masks, soil maps, phenology) and dynamic layers (weather variables).

Time series used in the WSI computation are all available with dekadal time step. A dekad is defined as the (roughly) 10-day period extending from day 1-10 of the month, 11-20 of the month, and 21-end of the month. Note that the dekad of the year is a circular variable, i.e. dekad 36 is followed by dekad 1.

The base grid resolution is set to the one of the land surface phenology layers (about 1 km). Some data are available at a coarser spatial resolution of 0.25 degrees such as weather data and crop coefficients. These data are linked to the base grid resolution.

All the WSI computations are made within a database environment (Oracle).

2.1 Weather data

Weather data is taken from the MARSOP project repository[1]. Data are originally gathered from the European Centre for Medium-Range Weather Forecasts (ECMWF) forecasting system. Compared to other rainfall data sources, ECMWF models additionally provide near real-time estimation of other weather elements such as air temperature, global radiation, wind speed and humidity that are used for the estimation of potential evapotranspiration component of the WSI.

The time series obtained from the ERA-Interim reanalysis model is used for the period spanning from 1989 up to the year preceding the current one. ERA-Interim variables are produced at 3-hourly time-step at a spatial resolution of approximately 80 km. Data from the current year up to the time of analysis are from the high-resolution forecast model (HRES), originally produced (at 00 and 12 UTC) with a 3-hourly time-step and approximately 9 km spatial resolution (ECMWF, 2015) and then gridded to a 0.25° resolution. While HRES forecasts are produced for the next 10 days, only those of the first day of this 10-day forecast depth, considered more reliable estimates of actual precipitation, are retained here and used to compute daily precipitation values.

The 3-hourly data of ERA-Interim and HRES are aggregated into daily data using indicator specific time zones and rules (see MARS wiki[2] for more information).

After computation of daily values, ERA-Interim is then scaled to the reference grid of HRES, including bias correction for all elements except precipitation (see Annex I) and then temporally aggregated to 10-day values. The combination of different models (ERA-Interim and HRES) is used because the ERA-Interim reanalysis model is not available in near real-time.

Data are then mapped to the base grid cell of 1 km resolution.

2.2 Masks

The WSI is computed separately for croplands and rangelands. The ASAP global cropland and rangeland masks are used. The following description refers to the ASAP masks at the time of writing (July 2018). As the ASAP masks are subjected to frequent updates, the reader is referred to the latest ASAP manual available at https://mars.jrc.ec.europa.eu/asap/asap-info.php.

The cropland and rangeland masks were derived by combining different land cover datasets into an optimal one. In Africa, the hybridization relied on a multi criteria analysis (MCA) using: accuracy assessment, agreement with FAO agricultural statistics, being up-to-date, expert-knowledge evaluation, and spatial resolution. The MCA was applied at country-level to compare six global products (i.e. GLC2000, GLCNMO2008, GlobCover

[1] https://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Welcome_to_WikiMCYFS
[2] https://marswiki.jrc.ec.europa.eu/agri4castwiki/index.php/Meteorological_data_from_ECMWF_models

2009, GlobLand30, LC-CCI2010, MODIS land cover 2010) and 16 regional land cover datasets (Pérez-Hoyos et al., 2017a). For the rest of ASAP countries, we compared the six global datasets plus FAO GLC-share and LC-CCI2015 using accuracy assessment and agreement with FAO agricultural statistics as criteria (Pérez-Hoyos et al., 2017b). For the U.S., Canada, Mexico, Europe, Australia, Afghanistan and Argentina we used regional datasets. For Russia we use Bartalev et. al (2016) only for cropland. See Meroni et al. (2018) for regional mapping details. Elsewhere, FAO GLC-share (Latham et al., 2014) was used.

To delineate rangeland areas we used the definition of grasslands used by FAO-GLCshare. Thus rangelands are defined as the class that includes any geographic area dominated by natural herbaceous plants with a cover of 10% or more, irrespective of different human and/or agricultural activities, such as grazing. Woody plants (tree and/or shrubs) can be present assuming their cover is less than 10%.

The masks, derived from cropland and rangeland maps with spatial resolution of 300 m or finer (various national land covers listed above), are expressed at the lower spatial resolution of the base grid system (1 km) as area fraction images (AF, i.e. the percentage of the pixel occupied by crop and rangeland, ranging from 0 to 100%). WSI is computed for any grid having and AFI greater than zero.

2.3 Phenology

Phenology is here derived from remote sensing 10-day MODIS NDVI (Normalized Difference Vegetation Index) imagery at 1 km spatial resolution over the period 2003-2016 processed according to Klisch and Atzberger (2016) and provided by BOKU University, Wien, Austria. Because the spatial resolution of this imagery fails to detect individual plant species but instead observes a combined signal of a larger surface, 'land surface phenology' (LSP) is the common term used for such assessments.

Phenological parameters used for WSI calculation are: the start of season (SOS), the moment of maximum (TOM) green vegetation cover, the senesce period (SEN), the end of season (EOS) and the resulting growing season length (GSL). Phenological timings are expresses as dekads.

The identification of phenological parameters from satellite data is made by analyzing the temporal evolution of NDVI using the SPIRITS software (Eerens et al., 2014; Rembold et al., 2015). With this approach we identify a maximum of two growing season per year. The naming of the two season as first and second has no biophysical connotation, it only reflects the fact the first season shows a maximum development that occurs earlier in the calendar year. The SOS is deemed to occur when NDVI grows above the 25% the ascending amplitude, SEN and EOS when NDVI drops below 75 and 35% of the descending amplitude, respectively. TOM occurs at the time when NDVI is at its maximum.

2.4 Soil data

Soil properties used in WSI computation are retrieved from the dataset WISE30SEC version 1.0 (Batjes, 2015). This dataset makes use of Harmonized World Soil Database (HWSD), including detailed soil maps for some parts of the world like Europe and China (1 to 1 million). Soil characteristics as available water capacity are based on an increased number of soil profiles compared to the previously used WISE version 1.2, increasing the accuracy of these characteristics.

Data have been processed to extract soil physical characteristics used in WSI (i.e. maximum rooting depth and available water capacity) for each soil type unit.

The soil maximum rooting depth is computed as the depth of the lowest soil layer. The available water capacity (cm m^{-1}) is computed by summing the available water capacity of each layer, corrected for the coarse fragments.

2.5 Crop type maps

The MAPSPAM crop maps (You et al., 2014) are used to spatially located crops types globally. Crop type specification is needed in WSI computation to select the correct crop coefficients. Using a variety of inputs (crop statistics, land cover, crop suitability, population density, etc.), SPAM uses a cross-entropy approach to make plausible estimates of crop distribution within disaggregated units. MAPSPAM crop maps are provided at 10 km spatial resolution, and here aggregated to a 0.25 degrees resolution in order to calculate area-weighted average crop coefficients (Kc and rooting depth), representing a generic arable crop, while reflecting the local crop composition of the 0.25 degree pixel (see section 3.3). One pragmatic reason to aggregate to 0.25 degree grid is that we strive to a minimum number of simulation units. Note that we do not simulate each individual 1 km grid cell but only the unique combinations of a given phenology with a 0.25 degree grid cell. Maintaining the 10 km resolution/variation of the crop composition would have thus led to more simulation units.

2.6 Crop coefficients

Crop evapotranspiration needed to compute the WSI is calculated with the FAO approach termed the 'Kc ET0', whereby the effect of the climate on crop water requirements is given by the reference evapotranspiration ET0 and the effect of the crop by the crop coefficient Kc. That is, experimentally determined ratios of ETc/ET0 (ETc being the crop specific evapotranspiration), the so-called crop coefficients (Kc), are used to relate ETc to ET0.

Here we used the so-called single crop coefficient approach and the Kc crop coefficients from the work of Allen et al., 1989 (list also available at http://www.fao.org/docrep/X0490E/x0490e0b.htm). In addition, we used also crop specific rooting depths from the same reference. For the rooting depth, we selected the minimum value of the defined range.

2.7 Agro-ecological systems considered

Two target agro-systems for WSI computation are defined:

- Generic arable crop based on the intersection between crop mask and MODIS phenology;
- Generic grassland based on the intersection between rangeland mask and MODIS phenology: rotated grazing and extensive grazing.

To these two generic agro-systems individual crops have assigned to allow the calculation of crop coefficient curves and crop specific rooting depth.

3 Methods

3.1 WSI calculation

The WSI is based on the FAO Crop Specific Soil Water Balance (CSSWB, Frere and Popov, 1986) allowing to assess the impact of weather conditions on crops.

According the FAO CSSWB, the water balance accounting scheme is:

$$W_i = \min(SWS, W_{i-1} + P_i - AETc_i) \qquad (1)$$

Where the subscript *i* refers to the dekad within crop cycle, W is the available water stored in the soil at the end of dekad, P is the cumulative rainfall during the dekad, and AETc is the cumulative actual crop specific evapotranspiration during the dekad. All variables are express in mm.

SWS is defined as the total amount of available water that can be stored in the soil within the plant's root zone. It is thus a fraction of the total amount of water that a soil can store, i.e. the one that can extracted by the plant roots at their maximum depth. The SWS is the difference between the soil water content at field capacity (FC) and wilting point (WP), taken for the whole maximum rooting depth (RD):

$$SWS = (FC - WP) * RD \qquad (2)$$

Rooting depth is the minimum depth between the crop specific maximum rooting depth and the soil maximum rooting depth. SWS is the simple the multiplication of available water capacity and rooting depth as defined above.

The soil water reservoir is simulated as a simple bucket with a number of approximations. When the amount of water in the soil ($W_{i-1} + P_i - AETc_i$) exceeds the soil water storage capacity (SWS), the excess rainfall is accounted for as water surplus or deep percolation. This is describe by the min operator that resets W to SWS if the calculated water amount exceeds SWS.

Run-off is not taken into account because the selected (time and spatial) scales are not suitable (too coarse) to determine local run-off. At the working spatial scale, run-off and run-on is assumed to average out. Therefore, it is assumed that all rainfall is effective (i.e. actually added and stored in the soil).

The potential evapotranspiration is the amount of evapotranspiration that occurs if sufficient water is available. It is a measure of water demand and represents the water requirement of the crop.

The potential crop evapotranspiration is the water requirement for the crop, defined as:

$$PETc_i = Kc_i * ET0_i \qquad (3)$$

Where the subscript *i* refer to the dekad within crop cycle, Kc is the FAO crop coefficient (Allen et al., 1998), ET0 is the cumulative reference evapotranspiration during the dekad according to Penman-Monteith estimation. Crop coefficients are crop and development stage specific and indicate the water demand of that crop at that stage relative to the reference crop.

Although water is theoretically available until wilting point, AETc is reduced well before wilting point (SWS = 0) is reached. When soil water is close to field capacity, water can be extract easily to meet the demand (AETc = PETc). As the soil water content decreases, water becomes more strongly bound to the soil matrix and the actual evapotranspiration (AETc) is smaller than the potential one.

This is modelled by linearly reducing AETc from PETc to 0 when the soil water content varies from a critical threshold (i.e. the critical soil water, SWC) to wilting point (Allen et al., 1998).

The soil water available to the plants during dekad *i*, is the sum of the water available at the end of the previous dekad (W_{i-1}) and the dekadal precipitation:

$AW_i = W_{i-1} + P_i$

Thus, the actual evapotranspiration (AETc) is computed differently according to the two conditions reported in Table 1.

Table 1. Computation of AETc

Condition	AETc	Description
AW ≥ SWC	AETc = PETc	The water content is above the critical threshold, no reduction
AW < SWC	AETc = (AW/SWC)*PETc	The water content is below the critical threshold, reduction proportional to the ratio AW/SWC

After that, we check if the computed AETc is actually available in the soil. If this is not the case, AETc is reduced to the available soil water:

If (AETc > AW) then AETc = AW (4)

The critical soil water SWC varies with growth stages and it is define as:

$SWC_i = SWS * RD_f * SW_f$ (5)

RD_f is the rooting depth fraction, ranging from 0 (emergence) to 1 (mature crop) during the growing season. It is noted that since the ASAP WSI starts at SOS (when the biomass-related NDVI value is 25% of the signal at maximum development), our RDf ranges from 0.25 (at SOS) to 1 (at TOM and afterwards). The root depth fraction is meant to simulate a young crop withstanding dry soil profiles thanks to light rain showers that replenish the upper root zone where the young crop's roots are concentrated. The root depth fraction concept secures that, at the initial stage, SWC is smaller and thus all rainfall is used for ETc despite a complete dry soil.

SW_f is crop specific and fixed in our application. Theoretically it can vary between 0 to 1 and it is the soil water fraction that can depleted A drought-tolerant crop will have a SW_f close to 0, indicating that PETc is not reduced when soil gets dry. On the contrary, its value will be higher for a drought-sensitive crop. Despite SW_f is crop specific (varying between 0.35 and 0.55 according to Allen et al., 1998) and also depends on the evaporative power of the atmosphere, here we fix it to a value of 0.45 as in Senay and Verdin (2003).

The main output of CSSWB is the Water Satisfaction Index (WSI) that inform on how well the crop water requirements were met over the period of interest within the crop cycle.

Compared the original CSSWB where the period of interest was the full crop cycle, here the WSI is computed over the realized crop cycle, from SOS till the dekad of interest (DOI) that can vary between SOS and EOS.

The WSI is a thus qualitative index expressing the percentage at which the crop water requirements have been met. It is calculated by summing the dekadal values of AETc over the realized crop cycle and dividing this sum by the total water requirement of the crop over the same period:

$$WSI = 100 * \frac{\sum_{i=1}^{DOI} AETc_i}{\sum_{i=1}^{DOI} PETc_i} \qquad (6)$$

The WSI is an index between 0 (when AETc was zero all the times, i.e. with no rain and a dry soil) and 100 (no deficit, i.e. PETc always met by AETc) that decreases when water stress is experienced.

Values close to 100 indicate, in the absence of other negative “non-weather” factors (i.e. pests, diseases), that expected yield should not depart too much from the local maximum. Generally, if interpreted in a qualitative way, a WSI value equal to 100 indicates no water stress and good crop yields, while a WSI below 50 corresponds to poor crop yield or crop failures.

3.2 Initialization of soil water

The initial soil moisture is an important input variable having significant influence on the final index. It is estimated by running a pre-seasonal soil water balance (PRE-SWB) model in which the presence of bare soil is assumed. The soil evaporation of the bare soil is set to (i.e. assumed equal to[3]) the reference evapotranspiration of Penman-Monteith reduced linearly for the ratio of the soil water and the soil water storage capacity, taking into the effect of mulching (drier soil reduces soil evaporation) in a simple way (only one soil layer is defined).

$Soil\_ETc_i = (W_i / SWS) * ET0_i$ (5)

The length of the initialization period is determined in an iterative way. The pre-seasonal run is started a short time before the SOS and is initialized using two extreme starting hypotheses: a soil dried until wilting point (“Sdry”) and a wet soil at field capacity (“Swet”).

These two runs result in two soil water content values at SOS. If these two values do not converge to a certain threshold, the initialization period is extended and the two runs are repeated iteratively until the criterion is reached. The retained value for the initial soil water content at SOS is then the average of the results of both runs.

The above threshold is defined as 1% of the total soil volume (for example 10 mm in case of 100 cm soil) meaning that the difference between the volumetric soil water content of both runs must be smaller than this 1%[4].

The initial length of the initialization period is 1 dekad. If convergence is not reached the period is extended with one dekad and run again etc. This is repeated until a length of 36

[3] It is noted that soil evaporation may be different from reference Penman-Monteith evapotranspiration. There is certainly room for improvement, e.g. use the potential ET of a wet soil without a canopy, switching to layered water balances etc. but that’s is currently beyond the scope of this global system.

[4] It is noted that is not SWS, it is about fractions of the total soil volume. One cubic metre of soil consists of water, solid particles and air. We check whether both runs have estimates of water volumes (expressed as fractions of the total volume) that are within 1% of the total soil volume. SWS is instead is the multiplication of the soil water content and rooting depth (expres.

dekads is reached which is the maximum initialization period. If the rates (rainfall and ETO) are high (e.g. in the tropics) the initialization period is rather short while for instance in cold and dry areas it could take much longer.

3.3 Assignment of Kc and rooting depth

In order to assign Kc crop coefficient and rooting depth to a specific crop grid cell we proceeded as follow.

The collection of crop grid cells (1 km spatial resolution) are specified by the crop mask described in section 2.2. Crop types are specified at 0.25 degrees resolution using MAPSPAM crop type maps as described in section 2.5.

We assume that all crop 1 km cells within the 0.25 degree crop type cell have all the same crop type composition, specified by the coarser grid cell.

The relative importance of each crop type is computed as the fraction of the area of a specific crop type over the total crop area in the 0.25 degrees grid cell.

As ASAP focus on food security, of all possible crop type that can be listed in 0.25 deg grid cell by MAPSMAP we retained only the staple crops. Perennial crops were excluded.

FAO Kc crop coefficients of the identified crop types within each 0.25 deg cell are retrieved and linked to the crop types present in the grid cell. In few cases a direct correspondence between crop types and the crops listed in Allen et al. (1989) could not be established and we proceeded as follow:

- Cassava: coefficients for cassava are specified for the first and second year of cultivation, we used the average over two years (Kc values not too different and no reason to take one of the two);
- Peas: coefficients are available for fresh and dry, we selected only dry beans as more relevant to food security;
- Wheat: coefficients are available for spring, winter, and winter with frozen soil wheat, we used the average of all of them (note that Kc values are nearly identical)
- Maize: we retained only field corn (i.e. ignored sweet maize);
- Sorghum: we retained only grain (i.e. ignored sweet sorghum).

With this data at hand, the weighted Kc average for that grid cell is computed (weights being the relative crop fraction). As a result, the final 0.25 degree specific crop coefficients are area-weighted averages of crop coefficients of individual crops assigned to the generic arable crop land. The list of the coefficients used in reported in

Table 2.

Table 2. Crop coefficients used.

Crop	Kc_ini	Kc_mid	Kc_end	Max root depth (cm)	SPAM long name	FAO names	FAO group
Cassava	0.300	0.952	0.400	60	cassava	cassava	roots&tubers or starchy roots
Potato	0.500	1.150	0.754	40	potato	potato	roots&tubers or starchy roots
Sweet Potato	0.500	1.150	0.650	100	sweet potato	sweet potato	roots&tubers or starchy roots
Sugar Beet	0.350	1.200	0.705	100	sugarbeet	sugarbeet	sugar crops
Beans, dry and Pulses	0.400	1.152	0.350	60	bean	beans, dry	pulses
Chick pea	0.400	1.000	0.350	60	chickpea	chickpea	pulses
Green Gram and Cowpeas	0.400	1.050	0.475	60	cowpea	cowpea	pulses
Groundnut (Peanut)	0.400	1.150	0.600	50	groundnut	groundnut, with shell	oilcrops
Lentil	0.400	1.100	0.300	60	lentil	lentils	pulses
Peas	0.500	1.150	0.300	60	pigeonpea	pigeon pea	pulses
Soybeans	0.400	1.150	0.500	60	soybean	soybean	oilcrops
Cotton	0.350	1.175	0.600	100	cotton	seed cotton	fibres
Rapeseed, Canola	0.350	1.075	0.350	100	rapeseed	rapeseed	oilcrops
Sesame	0.350	1.100	0.250	100	sesameseed	sesame seed	oilcrops
Sunflower	0.350	1.075	0.350	80	sunflower	sunflower seed	oilcrops
Barley	0.300	1.150	0.250	100	barley	barley	cereals
Winter Wheat	0.467	1.150	0.325	100	wheat	wheat	cereals
Maize, Field (grain) (field corn)	0.300	1.200	0.475	90	maize	maize	cereals
Millet	0.300	1.000	0.300	100	pearl millet	millet	cereals
Millet	0.300	1.000	0.300	100	small millet	millet	cereals
Sorghum	0.300	1.050	0.550	100	sorghum	sorghum	cereals
Rice	1.050	1.200	0.750	50	rice	rice	cereals
Sugar Cane	0.400	1.250	0.750	120	sugarcane	sugar cane	sugar crops

In the same way, crop rooting depth is computed as area-weighted averages of maximum crop rooting depth of individual crops.

For rangeland grid cell we used a combination of rotated and extensive grazing of Allen et al. (1989), i.e. a single Kc-curve and rooting depth specified as follows:

- Kc_ini: 0.35
- Kc_mid: 0.80
- Kc_end: 0.80
- Max root depth: 50 cm
-

3.4 Scaling of Kc curve to EO-based phenology

A link between Kc values and the EO-based phenology has been defined (Table 3). In the standard approach Kc is linked to the growing period length using the % progress of the season. According to the work of Allen (2003), in order to assign the proper weight at each dekad, the Kc value is linearly interpolated using 5 time "breakpoints". This timing scheme is "mimicked" by the EO-based phenological data providing 4 key timings (see Meroni et al., 2018).

Table 3. Link between Allen (2003) breakpoints and EO-based key phenological timings.

Breakpoints of Allen (2003)	**Allen's Kc**	**EO-phenology timings**	**Kc value assigned**
Planting	Kc_ini	-	
Start of growth	Kc_ini	SOS (time at which NDVI grows above the 25% the ascending amplitude)	Kc_ini + 0.25 * (Kc_mid – Kc_ini)
Full cover reached	Kc_mid	Time of Max (time of maximum NDVI)	Kc_mid
Start of senescence	Kc_mid	SEN (time when NDVI drops below 75% of the descending amplitude)	Kc_mid
Harvest or crop death	Kc_end	EOS (time when NDVI drops below 35% of the descending amplitude)	Kc_end

The only missing date is the planting date. Obviously planting cannot be derived from the moderate to coarse resolution EO-based time series. The first crop stage derived from the satellite based times series is SOS, that by definition happens after the planting time.

It was decided to skip the calculation of the water balance between planting and SOS and only start the calculation from SOS. At SOS we should not use KC-INI but a value between KC-INI and KC-MID. If we assume that KC-INI is linked to the minimum of the NDVI amplitude and KC-MID is linked to the maximum of the amplitude, we must increase KC-INI with 25% of difference between KC-MID and KC-INI.

The water balance starts at SOS while applying an initial soil water estimated through an initialization procedure described in section 3.2.

4 Output data

All the processing is made in Oracle environment with dekadal time step. A daemon generates two raster files covering WSI for grassland and generic arable crop.

4.1 Format

- Standard ENVI file (plane binary)
- Name: WSI_yyyymmddC0X.img.gz (first day of composite, crop = 1) and WSI_yyyymmddC0X.hdr, where yyyymmdd is the date and X is 3 for rangeland and 4 for cropland
- Rounding WSI to closest integer
- Flag values >= 251
- Byte type
- Header includes legend information: values = {WSI, %, 0, 100, 0, 100, 0, 1} and echo flags = {251 = no data, 252 = dekad out of season, 253 = season error}

4.2 Normalization of WSI

The automatic warning classification of ASAP works with anomalies to spot occurrences of below normal condition in precipitation and NDVI, regardless that absolute magnitude of the variable. Thus, like for NDVI also WSI must follow post-processing to determine anomalies.

Theoretical considerations and preliminary analysis of WSI distribution (pdf) per pixel and per dekad showed that the pdf of WSI changes over time, roughly moving from a distribution skewed to the right (of the 0-100% x-axis) at the first dekad of the season, to a symmetric normal at half-way through the season, to a left skewness at the end. An approach similar to that of SPI to compute a parametric anomaly was tested and found to be performing no better than the non parametric non-exceedance probability (NEP, also referred to as the percentile rank).

$NEP_d = rank(WSI_d)/(n+1) * 100$

Where WSI_d is the NDVI at dekad d (d = 1, .., 36) and n is the total number of samples (25 years at the time of writing). The rank is determined by arranging the data in ascending order (i.e. rank 1 is assigned to the smallest element in the sample).

NEP can be considered a non-parametric robust version of the standard score. In fact, under the assumption of normality of the data, standard score can be translated into a probability of non-exceedance (and vice-versa). Note that this relationship is used in ASAP to map NEP values into standard score for comparability with other anomalies.

4.3 Observed shortcomings

WSI showed consistent and expected spatial and temporal patterns. In small number of locations the initial value of WSI (at 0% progress) was 0 in the majority of the years. The problem seems to be related to misalignment between land surface phenology SOS and ECMWF ERA-interim precipitation onset. When SOS is earlier than usual rain occurrence WSI tends to be very low. In most of the cases SOS estimation seems to be realistic. In a minority of cases SOS estimates are unrealistic. Alternative rainfall data sets (e.g. ERA5) might (partially) solve this issue.

5 Way forward

First of all, there is an urgent need to improve on the rainfall data sources. Currently we use the ECMWF ERA-Interim data, in combination with the HRES data, because of its complete spatial coverage and coherence with other weather elements. However, the spatial resolution of the ERA-Interim is rather coarse (~80 km) and we have to complete time series with the HRES model as ERA-Interim comes available with a time lag of > 3 months. For some locations this transition from ERA-Interim to HRES introduces sharp gradients that negatively influences anomaly analysis. One of the most promising global data sets that soon will come available is the ERA5 data of ECMWF. It has a much finer resolution (~30 km). Still, NRT availability remains a problem. In the most positive scenario the time lag will be around 5 days which might be sufficient.

Concerning the WSI algorithm we the following possible improvement. The WSI calculation could become more accurate if we switch to a daily water balance (or even to another e.g. simple water bucket balance as implemented in WOFOST). This might have considerable impact on the technical performance which we first need to investigate.

In the current implementation we include all soil units with a water holding capacity and maximum rooting depth > 0 are included. This way we might include too poor soils that in fact are never cropped by farmers. To a certain extent this is solved as we only simulate for 1km pixels under the crop masks thus only locations where farmers do grow crops. Because of the SMU-STU concept of the soil data source, and thus the un-georeferenced STUs, we still might include poor STUs that a farmer would avoid. The WIS30SEC database offers more soil properties that could be used to filter non-suitable soil typologic units.

From technical perspective, we could work on further improvements of the performance. Processing the complete archive still takes 2-3 days. Ways to speed up performance are:

- Cache initial soil water;
- Improve the performance of joining the results to the fine 1 km grid;
- Only simulate the dominant soil type units.

References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. FAO - Food and Agriculture Organization of the United Nations. ISBN 92-5-104219-5. Rome.

Batjes, N.H., 2015. World soil property estimates for broad-scale modelling (WISE30sec, ver. 1.0). Report 2015/01, ISRIC—World Soil Information, Wageningen (available via: https://www.isric.online/sites/default/files/isric_report_2015_01.pdf)

Eerens, H., Haesen, D., Rembold, F., Urbano, F., Tote, C., Bydekerke, L., 2014. Image time series processing for agriculture monitoring. Environmental Modelling & Software, 53, pp. 154–162.

Frere, M. and G. F. Popov, 1986. Early agrometeorological crop yield assessment. Plant Production and Protection Paper No. 73, FAO, Rome.

Hartmann, H., 2011. Development of ERAI downscaling equations for the JRC global project. MC-MRD-CR-2011-002. Meteo Consult, Wageningen.

Klisch, A., Atzberger, C., 2016. Operational drought monitoring in Kenya using MODIS NDVI time series. Remote Sensing, 8(4), pp. 1-22.

Latham, J., Cumani, R., Rosati, I., Bloise, M., 2014. Global Land Cover SHARE (GLC-SHARE) database Beta-Release Version 1.0 – 2014. Available on line at: http://www.fao.org/uploads/media/glc-share-doc.pdf.

Meroni M., Rembold F., Urbano, F., Csak G., Lemoine G., Kerdiles H., Perez-Hoyoz A. (2018). The warning classification scheme of ASAP – Anomaly hot Spots of Agricultural Production, v2.2, doi: 10.2760/798528

Pérez-Hoyos, A., Rembold, F., Gallego, J., Schucknecht, A., Meroni, M., Kerdiles, H., Leo, O., Kayitakire, F., 2017a. Development of a New Harmonized Land Cover/Land Use Dataset for Agricultural Monitoring in Africa. WorldCover 2017 Conference, 14-16 March 2017, ESA-Esrin, Frascati, Rome (Italy).

Pérez-Hoyos, A., Rembold, F., Kerdiles, H., Gallego, J. Comparison of Global Land Cover Datasets for Cropland Monitoring, 2017b. Remote Sensing, 9 (11), 1118.

Rembold, F., Meroni, M., Urbano, F., Royer, A., Atzberger, C., Lemoine, G., Eerens, H., Haesen, D., Aidco, D.G., Klisch, A., 2015. Remote sensing time series analysis for crop monitoring with the SPIRITS software: new functionalities and use examples. Front. Environ. Sci. 3, 129–134.

Senay, G.B. and Verdin, J., 2003. Characterization of yield reduction in Ethiopia using a GIS-based crop water balance model. Canadian Journal of Remote Sensing, 29(6), pp.687-692.

You, L., U. Wood-Sichra, S. Fritz, Z. Guo, L. See, and J. Koo. 2014. Spatial Production Allocation Model (SPAM) 2005 v2.0. [date] Available from http://mapspam.info

Annex I

The ERA-Interim data, available at the 0.75 degree grid are downscaled to a regular global 0.25 degree grid (HRES grid) and then corrected. The method consists of two steps:

- Inverse distance weight interpolation (IDW) from the 0.75 degree ERA-Interim grid to the 0.25 degree HRES grid
- Bias correction between the IDW-interpolated ERA-Interim model and the HRES model for each 0.25 degree grid point for the following 6 parameters:
  - Mean temperature: T2M [ºC]
  - Maximum temperature: TX [ºC]
  - Minimum temperature: TN [ºC]
  - Dew point: TD [ºC]
  - Daily radiation sum: SSRD [kJ/m2/day]
  - Wind speed: FFM [m/s]

The daily data of the HRES model, available at the HRES grid for the period 2008-2010, is used as a training set to determine the bias correction. This has several advantages:

- The downscaling equation can be developed for each individual 0.25 degree grid cell.
- A possible bias between the ERA-Interim data and the HRES data set will disappear.

A linear regression equation between HRES and IDW-interpolated ERA-Interim data has been developed for each of the 721440 grid points, running in 0.25°-steps from 75°N to 50°S and 180°West to 180°East. For each grid point daily data of 2008-2010 was available from both the HRES and IDW-interpolated ERA-Interim data. The outcome is a linear equation:

$$Y_{i,j}^{ERAI-\mathrm{int},corr} = \alpha_{i,j} Y_{i,j}^{ERAI-int} + \beta_{i,j} + \left[T_{i,j}\right]$$

Where:

$Y_{i,j}^{ERAI-int}$ = ERA-Interim interpolated parameter (e.g. temperature, wind) for grid box [i,j]

$Y_{i,j}^{ERAI-\mathrm{int},corr}$ = ERA- Interim interpolated and corrected parameter for grid box [i,j],

$\alpha_{i,j}$ and $\beta_{i,j}$ = Correction coefficients (hereinafter referred to as slope and intercept, respectively)

$T_{i,j}$ = Additional parameter accounting for an additional seasonal correction as:

$$T_{i,j} = \gamma_{1,i,j} T_1 + \gamma_{2,i,j} T_2 + \gamma_{3,i,j} T_3 + \gamma_{4,i,j} T_4$$

In which T_1 to T_4 are sinusoidal time functions with a period of one year, and $\gamma_{1,i,j}$ to $\gamma_{4,i,j}$ are the respective coefficients.

For rainfall no corrections were applied. The rainfall parameter showed less accurate results in the regression due to its intermittent nature and distribution (see for more information Hartman, 2011).

As ERA-Interim rainfall is only interpolated and not bias corrected, the ERA-Interim rainfall can significantly deviate from the HRES rainfall.

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KJ-NA-29396-EN-N

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doi:10.2760/478822

ISBN 978-92-79-96678-1