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The warning classification scheme of ASAP – Anomaly hot Spots of Agricultural Production, v8.0

Technical description of warning classification system version 8.0

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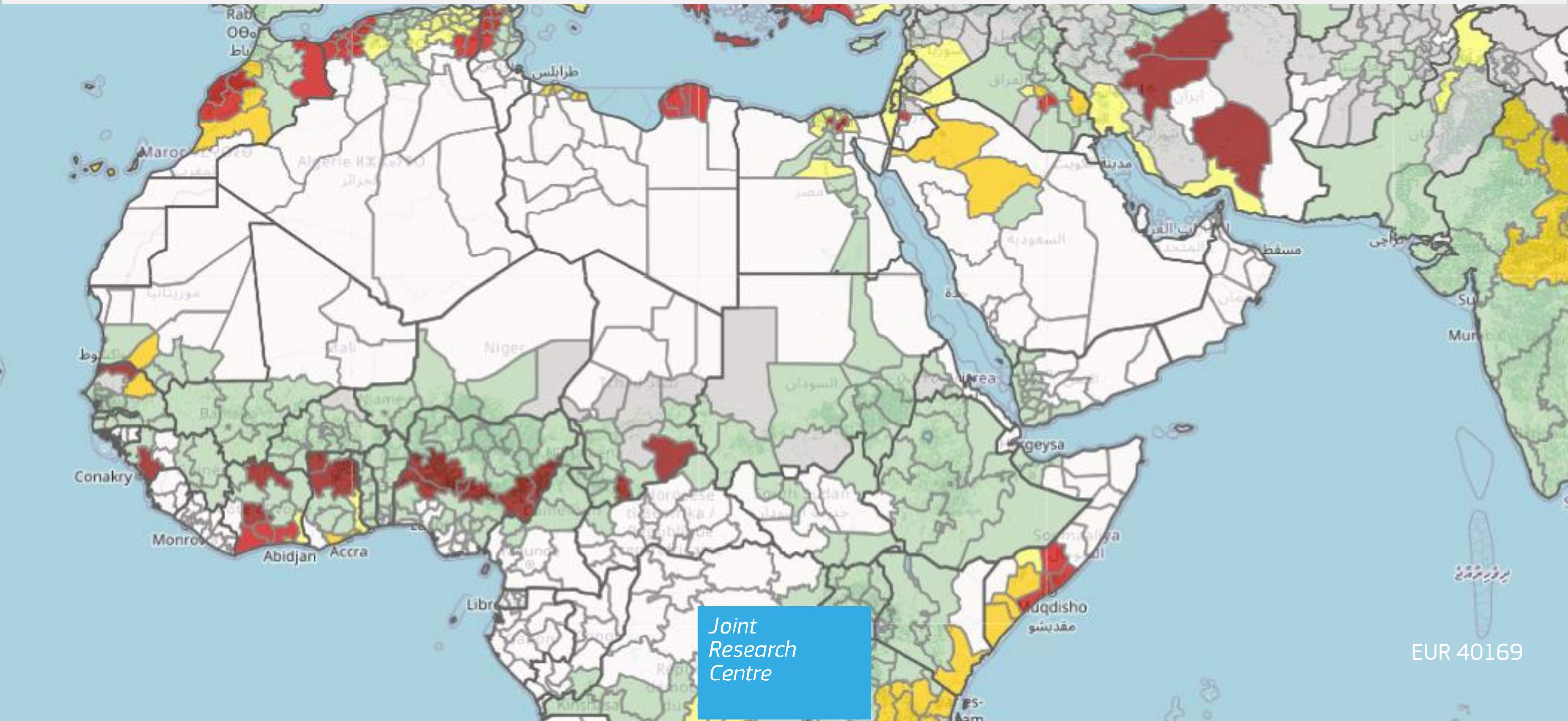

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Contents

Abstract

Agriculture monitoring, and in particular food security, requires near real time information on crop growing conditions for early detection of possible production deficits. Anomaly maps and time profiles of remote sensing derived indicators related to crops and rangelands conditions can be accessed online thanks to a rapidly growing number of web based portals. However, timely and systematic global analysis and coherent interpretation of such information, as it is needed for example for monitoring the United Nation Sustainable Development Goal 2 (Zero Hunger), remains challenging.

With the **ASAP** system (**Anomaly hot Spots of Agricultural Production**) we propose a two-step analysis to provide timely warning of agricultural production deficits in water-limited agricultural systems worldwide every month.

The first step is fully automated and aims at classifying each ASAP sub-national administrative unit (level 1 and 2, mostly corresponding to FAO Global Administrative Unit layer - GAUL 1 and 2 level, respectively) into a set of possible warning levels, ranging from "no warning" to "End-of-season biomass warning" (level 4). Warnings are triggered only during the crop growing season, as derived from a remote sensing based land surface phenology. The classification system takes into consideration the fraction of the agricultural land for each unit that is affected by a severe anomaly of soil water balance (measured through the Water Satisfaction Index, WSI), or precipitation deficit (measured through the Standardized Precipitation Index computed at the 3-month scale, SPI3), or vegetation biomass deficit (measured through a biophysical indicator of vegetation status, namely the anomaly of the cumulative value of the fraction of absorbed photosynthetically active radiation from the start of the growing season, FPARc), and the timing during the growing cycle at which the anomalies occur. The level (i.e. severity) of the warning thus depends on: the timing, the nature and number of indicators for which an anomaly is detected, and the extent of the agricultural area affected. Maps and summary information are published in the Warning Explorer platform, available at https://agricultural-production-hotspots.ec.europa.eu/wexplorer/.

The second step, not described in this technical report, involves the verification of the automatic warnings by agricultural analysts to identify the countries with potentially critical conditions at the national level that are marked as "hot spots" (https://agricultural-production-hotspots.ec.europa.eu/).

This report focusses on the technical description of the automatic warning classification scheme version 8.0.0.

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1 Introduction

Agricultural drought, with its negative effects on agricultural production, is one of the main causes of food insecurity worldwide. Climate variability and extremes, together with conflicts and economic slowdowns and downturns (recently exacerbated by socioeconomic impacts of COVID-19 pandemic and Russia's war against Ukraine) are major drivers of food insecurity and malnutrition. They are key drivers behind the recent rises in global hunger and among the leading causes of severe food crises (FAO et al., 2018; Food Security Information Network et al., 2022). Extremes have been increasing in both frequency and intensity, and are occurring more frequently as concurrent and compound events (FAO et al., 2021, IPCC, 2021). There is high confidence that increasing weather and climate extreme events have exposed millions of people to acute food insecurity and reduced water security, with the largest impacts observed in many locations in Africa, Asia, Central and South America, Small Islands and the Arctic (IPCC, 2022).

Crop failures and pasture/rangeland biomass production losses are the primary direct impact of drought on the agricultural sector productivity. Drought-induced production losses cause negative supply shocks, but the amount of incurred economic impacts and distribution of losses depend on the market structure and interaction between the supply and demand of agricultural products (Ding et al., 2011). These adverse shocks affect households in a variety of ways, but typically the key consequences are on assets (United Nations, 2009). First, households' incomes are affected, as returns to assets (e.g., land, livestock, and human capital) tend to collapse, which may lead to or exacerbate poverty. Assets themselves may be lost directly due to the adverse shocks (e.g., loss of cash, live animals, and impacts on health or social networks) or may be used or sold in attempts to buffer income fluctuations, affecting the ability to generate income in the future.

One way to mitigate drought impacts relies on the provision of timely information by early warning and monitoring systems that can be used to ensure an appropriate response (Rembold et al., 2016). Obviously, even if a drought can be timely forecast, having an operational early warning systems in place is only a first step towards ensuring rapid and efficient response (Hillbruner and Moloney, 2012).

The Joint Research Centre (JRC) of the European Commission has a long standing experience in monitoring agriculture production in food insecure areas around the world by using mainly agrometeorological, remote sensing and geospatial data. The first remote sensing based crop monitoring bulletin was published in 2001 for Somalia and was followed by similar products for other countries in East, West and Southern Africa over the following years. However, while this work addressed well country level information needs, the full potential of global data sets of remote sensing and weather information for monitoring agricultural production in all countries affected by risk of food insecurity, remained largely underexploited. Also, recent extreme climatic events with their impact on crop production in food insecure areas, such as for example the 2015/2016 El Niño, have confirmed the importance of global early warning systems. Finally, the JRC is involved in global multi-agency networks for agricultural monitoring such as the Global Agriculture Monitoring Initiative (GEOGLAM), promoted by the G20 international forum as part of the Group on Earth observations (GEO). This requires regular information to be made available for the two GEOGLAM flagship products, the Agricultural Market Information System (AMIS) crop monitor for main cereals producing countries and the Crop Monitor for Early Warning (CM4EW) for food insecure countries.

In order to fulfil the information needs of the Directorate General for International Partnerships (DG INTPA) of the European Commission for programming their food security related assistance and for making available timely early warning information to the international community, the JRC developed a free and open Early Warning system named ASAP (Anomaly hot Spots of Agricultural Production). ASAP addresses users with no expertise in processing remote sensing and meteorological data for agriculture monitoring and aims at directly providing them with timely and concise information about agricultural production anomalies caused by agricultural drought.

With ASAP we propose a two-step analysis to provide timely warning of possible production deficits globally.

The first step is described in this report and consists in an automatic warning classification system aimed at supporting the analysts in their country level assessment. Input data and results of such classification system are published in the ASAP Waring Explorer platform (https://agricultural-production-hotspots.ec.europa.eu/wexplorer/, https://agricultural-production-hotspots.ec.europa.eu/download.php).

The goal of the warning classification algorithm is to produce a reliable warning of possible agricultural production deficit at the level of administrative units (ASAP level 1 and 2, mostly corresponding to GAUL 1 and 2 level, respectively), with an homogeneous approach at the global scale. This is achieved through an automatic standard analysis of rainfall estimates, simulated water balance and observed (by remote sensing) biophysical status of vegetation, based on the assumption that these indicators are closely linked to biomass development and thus, to crop yield and rangeland production. The result is summarised into a warning level ranging from “no warning” to “End-of-season biomass warning” (level 4). The system is based on custom software written in house by the Joint Research Centre - D5 Food Security – ASAP Development Team and it is based on open source software. The ASAP software uses a combination of open source tools, mainly PostgreSQL, PostGIS, Python, PHP, Geoserver, and OpenLayers. The processing code is written in Python with the use of industry standard libraries for processing raster images, Rasterio, GDAL and numpy.

The second analysis step involves the verification of the automatic warnings by agricultural analysts to identify the countries (national level) with potentially critical conditions that are marked as “hot spots”. In their evaluation, the analysts are assisted by graphs and maps automatically generated in the previous step, agriculture and food security-tailored media analysis (using the Joint Research Centre Media Monitor semantic search engine), and the automatic detection of active crop area using high resolution imagery (e.g. Landsat 8, Sentinel 1 and 2), processed in Google Earth Engine. Maps and statistics, accompanied by short narratives are then made available on the website (https://agricultural-production-hotspots.ec.europa.eu/) and can be used directly by food security analysts with no specific expertise in the use of geo-spatial data, or can contribute to global early warning platforms such as the GEOGLAM, which perform a multi-institution joint analysis of early warning information.

In this technical report we describe the main features of the ASAP warning classification system version 8.0, publicly available at https://agricultural-production-hotspots.ec.europa.eu/wexplorer/. Section 2 introduces the base data layers used for the classification. Section 3 describes the spatial framework at which the classification system works. The methods used are described in Section 4, introducing the reader to the pixel-level analysis (4.1) and the aggregation at the administrative level used to identify the warning level (4.2). An example of the warning classification system is provided in Section 5 and conclusions are drawn in Section 6.

1 Data

1.1 EO and agrometeorological data

Global early warning monitoring systems for agriculture require timely and synoptic information about vegetation development (Rembold et al., 2015). Satellite products used for these purposes mostly refer to vegetation indices (e.g. the Normalized Difference Vegetation Index, NDVI) or biophysical variables (e.g. the Fraction of absorbed Photosynthetically Active Radiation, FPAR; the Leaf Area Index, LAI). Such products are mainly derived from space-based measurements of the reflected radiation in the visible to near infrared domain. Rainfall, a key driver of vegetation development especially in the water limited ecosystems targeted by ASAP, is often analysed to anticipate the effect of water shortage. In order to draw conclusions about the development of crops during an ongoing growing season, such key variables are analysed in near real-time and typically compared with reference years (for instance, a past year known for having had abundant or poor crop production) or with their historical average (here referred to as the Long Term Average, LTA). The use of remote sensing time series for crop and vegetation monitoring requires a number of processing steps that include the temporal smoothing of the missing or cloud-affected remote sensing observations, the computation of LTA and associated variability, the computation of anomalies, the detection of plant phenology and the classification of the productivity level on the basis of seasonal performances.

Input data should therefore have a global coverage and high acquisition frequency. In addition, a consistent archive of data records should be available to allow the computation of reliable measures of central tendency and dispersion.

The automatic warning classification of ASAP v8.0 is based on:

- 10-day rainfall estimate (RFE) products provided by: i) the European Centre for Medium-Range Weather Forecasts (ECMWF) for the whole globe at 0.25° spatial resolution; ii) the Climate Hazards Group (CHIRPS product) for the area comprised between latitudes 50S and 50N at 0.05° spatial resolution.
- 10-day composite of FPAR data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the continuity from the Visible Infrared Imaging Radiometer Suite (VIIRS) instruments at 500 m spatial resolution.
- 10-day estimates of the Water Satisfaction Index (WSI), an indicator of crop (or rangeland) performances based on the availability of water to the plants during the growing season at 500 m spatial resolution (spatial resolution of FPAR data as meteo data used by WSI have a coarser resolution that varies with the variable and latitude).

WSI is described in detail in the WSI technical report available in the info download page[1]. WSI uses ECMWF evapotranspiration and rainfall from CHIRPS between 50° N and 50° S and from ECMWF above and below this latitude band in a water balance accounting scheme to estimate water available to the plant. It is computed for cropland (rangeland) pixels and uses their phenology (derived from 500m FPAR LTA data) to compute their water requirement.

With the exception of CHIRPS rainfall estimates, weather data for ASAP are retrieved from the European Centre for Medium-Range Weather Forecasts (ECMWF) forecasting system. Since ERA5 reanalysis model data are available with a 6-day time lag, a combination of ERA5 reanalysis data and of ECMWF deterministic high-resolution forecast model (HRES) data is used. HRES is run twice

[1] https://agricultural-production-hotspots.ec.europa.eu/documentation.php

daily to forecast weather variables of the next 15 days. Only the first hours (i.e. the most accurate prediction) is retained for this processing line.

The time series of ERA5 data are used for the period spanning from 1981 up to date with a delay from 2 to 4 dekads. The ASAP meteo archive is updated with ERA5 data on the 20th of the month for the previous month, while HRES data is used for the latest dekads up to date. That is, on the 20 of month *m*, we update the ASAP meteo archive with ERA5 data up to the 20 of month *m*-1 and for the 3rd dekad of month *m*-1 and the first two dekads of month *m* we use HRES data. The delay between the ERA5 data availability and update in the ASAP system is to be in line with CHIRPS final dataset.

ERA5 variables are produced at hourly time-step and native spatial resolution of approximately 32 km. Data are obtained from the Copernicus Climate Data Store (CDS) and rescaled from the native model grid to a 0.25° lat/lon grid using ECMWF software. The data are aggregated to daily time step (taking into account different time zones) and bias corrected to be coherent with ECMWF HRES data for all variables except rainfall (for which no good calibration could be set). Near real time data are taken from HRES, originally produced at hourly time-step with approximately 9 km spatial resolution (ECMWF, 2015). HRES data are subsequently upscaled to 0.25° lat/lon grid using ECMWF software and then aggregated to daily data using the same aggregation methods as for ERA5.

CHIRPS 2.0 dekadal (10-day) data at 0.05° spatial resolution are downloaded from the Climate Hazards Group ftp site[2]. Final CHIRPS (all station data) is available sometime in the third week of the following month, preliminary CHIRPS data are available 2 days after the end of the dekad.

The time series of final CHIRPS data are used for the period spanning from 1981 up to date with a delay from 2 to 4 dekads. The ASAP meteo archive is updated with final CHIRPS data on the 20th of the month for the previous month, while preliminary CHIRPS data is used for the latest dekads up to date.

Daily CHRIPS data (together with daily weather data) are used in the WSI to improve the temporal resolution of the water balance model.

For rainfall above latitude 50N, ECMWF rainfall (ERA5 and HRES) is used as CHIRPS coverage is limited to latitudes between 50S and 50N.

CHIRPS, ECMWF and MODIS-VIIRS time series are available from years 1981, 1989[3] and 2000, respectively. Satellite-based phenology is computed using the long term average of the 19-year time series (2002-2020) of MODIS FPAR observations.

Box 1. MODIS-VIIRS processing chain for optimal noise removal and ensuring long term continuity

A dedicated processing line was established to produce a ready to use and high-quality long-term time series of MODIS-VIIRS FPAR updated in NRT for monitoring purposes, exploiting the long term archive of MODIS and guaranteeing sustainability of the production using VIIRS instruments.

[2] https://data.chc.ucsb.edu/products/CHIRPS-2.0/

[3] Original ECMWF data are available for a longer time span. We are referring only to the data used by the MCYFS (Mars Crop Yield Forecasting System)

We use an improved version of the MODIS data processing originally developed by Klisch and Atzberger (2016) applied to MODIS (Terra and Aqua) and VIIRS (on-board of SUOMI-NPP and NOAA-20 at the time of writing) FPAR data at 500 m.

The objective of the processing line is the production of quality improved (noise-removed and gap-filled) FPAR data for both the archive (past observations) and near real-time (NRT, current observations) 10-day composite MODIS and VIIRS 500 m FPAR from NASA. Latest collection of FPAR are used, MODIS FPAR timeseries (2000-now) is from collection 6.1 and the VIIRS FPAR time series (2012-now) is from collection 2. Details of the processing line are reported in Seguini et al. (in preparation).

Following the definition of Sedano et al. (2014), smoothing applies in a post hoc sense, where there is a need to interpolate past data in a time series. Filtering, on the other hand, is relevant in an on-line learning sense, in which current conditions are to be estimated from the currently available data.

At the start of the processing, the historical data is smoothed. That means this process is done only once using the entire time series up to the latest point in time. For smoothing, the Whittaker smoother was used (Eilers, 2003; Atzberger & Eilers, 2011a; Atzberger & Eilers, 2011b). The Whittaker smoother fits a discrete series to discrete data and puts a penalty on the roughness of the smooth curve. It is employed here to smooth and interpolate the data in the historical archive to daily FPAR values. The smoothing takes into account the quality of the observations according to the MODIS and VIIRS Quality Assessment Science Data Set (QA SDS, Didan et al., 2015). A smoothing lambda parameter of 3000 is iteratively applied to fit the upper envelope of the FPAR temporal trajectory, considering that higher FPAR values have lower the probability of cloud contamination while isolated drops are likely to be observation affected by undetected clouds, and implementing a stop criterion as in Chen et al., 2004.

Weights are assigned to the FPAR observations based on the QA SDS. From the output of daily FPAR time series, only the last daily value is stored forming a time series of 10-day (dekadal) images. That is, the 10-day composites have a fixed date corresponding to the end-point of the 10-day period (10, 20, last day of the month). From the smoothed 10-day images, dekadal statistics (average, dekad to dekad variations and inter-annual variability) are calculated describing the typical FPAR temporal trajectory for any grid cell.

The near real-time filtering is executed at the end of each 10-day period (dekad) estimating the state of FPAR based on the data that are available at that time including the past e.g. 190 days. The process is repeated in temporally overlapping windows. The filtering itself follows the same procedure and similar settings as described for the archive smoothing. In addition, we constrain the filtered values to force the filtered FPAR values to respect the historical average dekad-to-dekad variations when high quality observations are not available (Seguini et al., in preparation).

For each filtering step (for each 10-day period), the NRT filtering outputs six images. When we reach end of dekad D, we produce a filtered FPAR image for the this dekad for the first time (consolidation stage 0) and more consolidated versions of FPAR for the previous four dekads (D-1 at consolidation stage 1, D-2 at consolidation stage 2, D-3 at consolidation stage 3, and D-4 at consolidation stage 4) taking advantage of the increased availability of new observations. Obviously, consolidation stage 4 is more reliable (e.g. better constrained through available data) compared to stage 0.

The sixth and final image corresponds to the fully consolidated FPAR data at dekad D-9. This fully smoothed value is available only after 3 months (9 dekads) to take advantage of nine observations available to the left and right (e.g. back and forward in time). Hence, this output is of highest quality.

Associated with the production of each consolidation stage, quality flag images are produced: SMP, a status map indicating the filtering condition; NWM, the number of high quality observations between stages C4 and C0; QWM, the average weight of observations between stages C4 and C0; NLM, the number of days from the last high quality observation to the last day of the temporal window; and QLM, the weight of last available observation.

1.2 Cropland and rangeland masks

ASAP warnings are issued separately for cropland and rangelands. Cropland and rangeland area are identified by masks expressed as area fraction image (AFI, i.e. the percentage of the pixel area occupied by either cropland or rangeland, ranging from 0 to 100%).

The ASAP v.8.0 cropland AFI is derived by fusing two of the latest high resolution remotely-sensed cropland products: the European Space Agency's WorldCereal and the cropland layer from the University of Maryland. Details of the processing can be found in Fritz et al. (2024a[4]) and Fritz et al. (2024b). It is noted that, in the ASAP v.8.0 cropland AFI, additional high resolution mapping products (i.e. ESRI, GSFAD, ESA WorldCover) are used to complement the two main layers (i.e. WorldCereal and University of Maryland) in case of strong disagreement between the two or in the presence of large errors of the fused product as assessed by JRC ASAP analysts (Fritz et al., 2024a). In addition, to ensure compatibility with the JRC agricultural monitoring in the EU, for Europe we directly sourced the CORINE 2018 used by the JRC Agri4Cast team for the elaboration of their crop monitoring bulletins. Specifically, classes 211 (non-irrigated arable land), 212 (irrigated arable land) and 213 (rice fields) from CORINE 2018 were selected for the European Union extent.

For our purposes, we adopt the GLAD definition for the hybrid herbaceous annual cropland map: land used for annual and perennial herbaceous crops for human consumption, forage (including hay) and biofuel. Perennial woody crops, permanent pastures and shifting cultivation are excluded. The fallow length is limited to 4 years for inclusion as cropland. For a thorough discussion on the caveats of crop and rangeland definition when fusing different products see Fritz et al. (2024a).

The functional definition of rangeland is specific to the ASAP Early Warning System. Such a warning system should focus on all areas where grazing can happen, and this clearly includes grassland and shrubland. In addition, as ASAP monitors rangeland for food security purposes, the key aspect to be considered is the capacity of an area to sustain livestock. We are thus interested in creating an AFI that provides the relevance of the pixel in producing biomass to support animal.

For sustaining livestock, the herbaceous component is obviously fundamental. Nevertheless, shrub areas are also used for grazing in semi-arid areas. However, shrub biomass productivity is smaller than that of grassland. Shrub biomass may be large, but annual productivity is typically lower than that of grassland (Gherardi and Sala, 2015). In addition, only some shrubs may be palatable and then only for some animal species, like camels or goats. During a severe drought, shrub may be more persistent and greener than grassland but with very low productivity. Taking into account the greater importance of the herbaceous layer, we opted for defining our rangeland AFI by considering both grassland and shrubland, but giving more credit (i.e. weight) to grassland.

After inspection of land use land cover products providing grassland and shrubland classes, the ESA World Cover at 10 m v200 was found suitable for our rangeland mask. The definitions of the two classes in this product are reported below.

Grassland - This class includes any geographic area dominated by natural herbaceous plants (plants without persistent stem or shoots above ground and lacking definite firm structure) like grasslands, prairies, steppes, savannahs, and pastures with a cover of 10% or more, irrespective of different

[4] https://agricultural-production-hotspots.ec.europa.eu/files/JRC137153_Development_of_a_new_cropland_and_rangeland_Area_Fraction_Image_at_500_m_for_the_ASAP.pdf

human and/or animal activities, such as: grazing, selective fire management etc. Woody plants (trees and/or shrubs) can be present assuming their cover is less than 10%. It may also contain uncultivated cropland areas (without harvest/ bare soil period) in the reference year (i.e. 2021 in this case).

Shrubland - This class includes any geographic area dominated by natural shrubs having a cover of 10% or more. Shrubs are defined as woody perennial plants with persistent and woody stems and without any defined main stem being less than 5 m tall. Trees can be present in scattered form if their cover is less than 10%. Herbaceous plants can also be present at any density. The shrub foliage can be either evergreen or deciduous.

In the development of the rangeland AFI, the two classes have been weighted differently to assign more importance to grassland. Before resampling the 10 m layers to 500 m, weights of 100% and 50% have been assigned to grassland and shrubland, respectively.

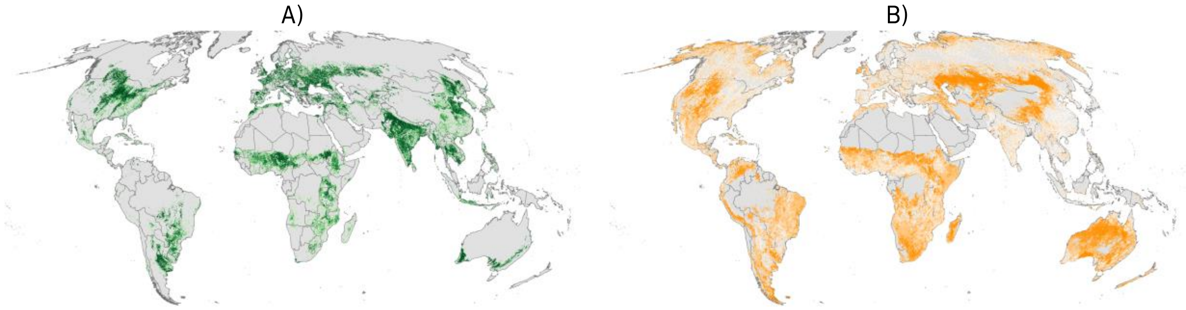
As for cropland, to ensure consistency with JRC Agri4Cast monitoring in the EU, for Europe we directly sourced the 10 m Copernicus Grassland High Resolution Layer[5].

Finally, as we give more credit to the new cropland AFI, we limited the %AFI of rangeland by subtracting the percentage of crop present at the same location. The final area fraction was therefore derived as $AFfinal$ = min ($AFrangeland$, 100 − $AFcrop$). More information on the rangeland AFI can be found in Fritz et al. (2024a).

The resulting AFIs are presented in Figure 1.

Figure 1. ASAP v.8.0 cropland (A) and rangeland (B) AFIs.

A) B)



Source: JRC

2 Geographic coverage

The automatic warning classification capitalizes on the global availability of the climatic and remote sensing indicators and is applied globally. At the sub-national level all classified warnings are made available in a web-GIS page named “Warning Explorer” (https://agricultural-production-hotspots.ec.europa.eu/wexplorer/).

[5] https://land.copernicus.eu/pan-european/highresolution-layers/grassland/status-maps/grassland-2018?tab=download

Concerning the final hot spot identification at the national level only, the automatic warning information produced for 73 countries worldwide is retained and evaluated further by the analysts. These countries were selected in accordance with:

1) the need of food availability information of the European Commission (EC) for countries where food security is a priority sector for the European Development Fund (EDF) programming;
2) the aim of contributing to the GEOGLAM Crop Monitor for Early Warning which provides information for countries with a high risk of food insecurity.

The list includes most of the African continent and selected countries in Central America, Caribbean region, and Central and South East Asia (till North Korea in East Asia).

2.1 Spatial framework

2.1.1 Spatial unit of analysis and ASAP levels

Warning and associated information are computed at two levels of increasing spatial granularity: ASAP levels 1 and 2. The two levels build on administrative units from Food and Agriculture Organization (FAO) Global Administrative Unit Layers (GAULs). Working with administrative units instead of agro-ecological or livelihoods units has the advantage that administrative units are well recognised by users and they can be easily linked with statistical data normally available at the administrative level (crop types, calendars, area and yield statistics, etc.).

GAUL levels used in ASAP range from 0 (country) to 2 (second sub-national administrative subdivision). The GAUL level used in different countries was identified as a reasonable compromise with regards to the trade-off between the need of analysing units with homogeneous agro-ecological characteristics (ideally small units) vs. the need of summarizing the results for a global outlook (ideally large units). ASAP levels attempt to homogenize the dimension of the units globally (i.e. avoid the presence of extremely large and extremely small units in the same ASAP level). To this aim, ASAP levels 1 and 2 have been adapted for particular cases and as a result do not always correspond to GAUL levels 1 and 2.

For example, although ASAP level 1 corresponds in most of the cases to GAUL1 (the first sub-national administrative regions), in some small countries (e.g. Iceland, Switzerland) it corresponds to GAUL0 (i.e. the country boundaries) to avoid the use of very small units.

ASAP level 2 represents a compromise between the need of an increased granularity and system performance and functionality. Opting for the most detailed level (GAUL2) for all countries, including those where it is not significant to have a large granularity or those that are not typically inspected by ASAP analysts or ASAP public users, would increase the total number of units considerably. This would put an unnecessary strain on the system and could jeopardise normal functioning and timely execution of processing. Therefore, GAUL2 level was adopted for 62 countries to support the Integrated Food Security Phase Classification (IPC) and Cadre Harmonisé (CH) analyses, operationally carried out at GAUL2 level. Where IPC analysis is performed at GAUL1 level, we used it for ASAP level 2 (i.e. Guatemala, El Salvador). GAUL2 level is also employed for various countries of interest to public ASAP users (e.g. various countries in Europe, the U.S.A., India, etc.). In all other countries, the same GAUL1 level is used in both ASAP levels. In certain countries, although ASAP level 2 units originate from the same GAUL1 level used in ASAP level 1, there may be minor variations in the unit boundaries. This is a known discrepancy planned to be resolved in future versions of the system.

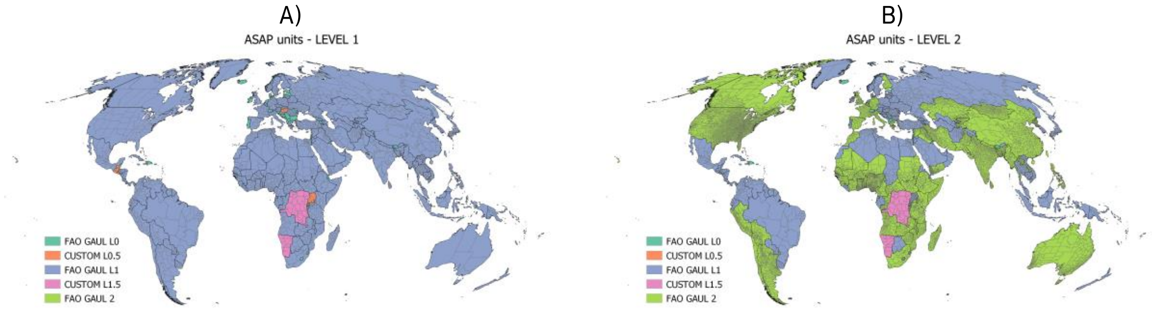
Special rules were used for the following countries: Chad, DRC, Namibia, Uganda, El Salvador, Guatemala and Hungary. In Chad we used for both ASAP levels the updated administrative units obtained from the Ministry of Agriculture in place of outdated GAUL1. In DRC we used the province unit layer with granularity roughly between GAUL1 and 2 for both ASAP levels. In Namibia we used GAUL1 for both ASAP levels and updated it with the split Kavango into East and West operated by the government in 2013. Finally, in El Salvador, Guatemala, Uganda and Hungary we used local administrative units larger than GAUL1 for ASAP level 1 and GAUL1 for ASAP level 2. When administrative boundaries with granularity between GAUL levels (referred to as 0.5 and 1.5 in Figure 2), these are country specific boundaries.

In all cases, the geometry of the administrative units was simplified (e.g. the number of vertex reduced and small islands removed). In particular:

- When the average size of GAUL1 units within a GAUL0 is less than 5000 km^2, all GAUL1 units are merged together and the GAUL0 polygon is used as the ASAP level 1 unit. An exception to this rule is applied in Africa to avoid oversimplification in the some countries of interest: merging is not applied if the GAUL0 size is greater than 25000 km^2.
- Suppression/merging of negligibly small ASAP units. All the resulting single polygons with a total area smaller than 200 km^2 are considered too small to be relevant at the working scale of ASAP and are thus merged with the neighbouring polygons (of the same country) or excluded (in case of islands).

Figure 2 show the ASAP administrative details per country and per ASAP level (1 and 2).

Figure 2. ASAP v.8.0 unit granularity at level 1 (A) and level 2 (B). Custom levels L0.5 and L1.5 are country specific administrative regions that have a granularity between GAUL0 and 1, and GAUL1 and 2, respectively.



Source: JRC

All adjustment described above were put in place for technical considerations and do not imply a position of the European Commission.

2.1.2 ASAP units marked as "No cropland/rangeland"

Some of the above defined units are systematically not analysed by the warning classification system because their agricultural area is considered too small. Total crop and rangeland areas are calculated per ASAP unit using the respective AFIs (Section 1.2).

Countries with crop/rangeland area < 250 km^2 (MTATG0 threshold) are considered of minor importance and excluded.

In addition, an ASAP unit is not analysed when at least one of the two conditions is met:

1) The crop (or rangeland, depending on what target is being analysed) area is smaller than 25 km^2 (MTAT threshold). Below this threshold, the sample size of grid cells on which ASAP is working might be statistically insufficient for reliable results.

2) The crop area (or rangeland, depending on what target is being analysed) is less than 0.25 % of unit area (MTAT% threshold), indicating a very marginal crop (or rangeland) importance in the unit.

Note: in the Warning Explorer, when changing the level of analysis from level 1 unit to its level 2 sub-units, some of the level 2 units may not be analysed. Although counterintuitive, this is typically due to the condition 1 not being met for some level 2 units. That is, the crop (rangeland) area is larger than 25 km^2 for the level 1 unit but it is smaller than that this threshold for one or more level 2 units.

Finally, ASAP units with a cattle equivalent density smaller than 0.5 units km^{-2} (CED threshold) are excluded from the rangeland analysis. Cattle equivalent density is taken from Robinson et al. (2014).

Note that crop and rangeland are considered separately. So a given unit may be excluded from the cropland analysis but not for the rangeland analysis, and vice-versa. Not analysed units are marked as "No crop/rangeland" in the Warning Explorer.

3 Methods

Although an ideal monitoring system would be crop specific, we recognize that crop specific global maps are not fully available. In addition, crop specific maps would need to be updated every year as crop location is not constant over time due to rotation practices, for instance. Therefore, our analysis is performed separately for generic cropland and rangeland areas. No distinction among different crops is thus considered. For simplicity and conciseness, in the following description we will refer to the cropland layer only.

As mentioned before, the warning classification is applied separately at the two levels of spatial detail (ASAP level 1 and 2). However, substantial processing is made at the pixel level to compute the indicators on which the classification is built upon. This processing is described in Section 3.1. Once the pixel-level indicators are computed, they are aggregated at the administrative unit level and used in the classification for the warning (Section 3.2)

3.1 Pixel-level analysis

The main indicators used by the classification system (Table 1) are computed at the pixel level every 10-days, when new observations are ingested in the system. Indicators rely on the per-pixel definition of the land surface phenology, described in the following section.

Table 1. Indicators used in the warning classification system. Detail in Section 3.1.2.

mFPARd	[Anomaly] Mean FPAR difference with historical average over the growing season period experienced until the date requested. Note that the growing season may start at different time in different pixels.
zFPARc	[Anomaly] Standardized score (Z-score) of the cumulative FPAR over the growing season period experienced until the date requested. It indicates how many standard deviations the cumulative FPAR is away from its mean value.
zWSI	[Anomaly] Standardized score (Z-score) of the WSI over the growing season period experienced until the date requested. Anomalies in WSI are first computed as non parametric non-exceedance probability (NEP), which is then translated into a Z-score for compatibility with other indicators.
SPI3	[Anomaly] Standardized precipitation Index computed with 3-month time scale. The SPI is a probability index that expresses the observed cumulative precipitation for a given timescale (i.e., the period during which precipitation is summed) as the standardized departure from the rainfall probability distribution function.

Source: JRC

3.1.1 Computation of remote sensing phenology

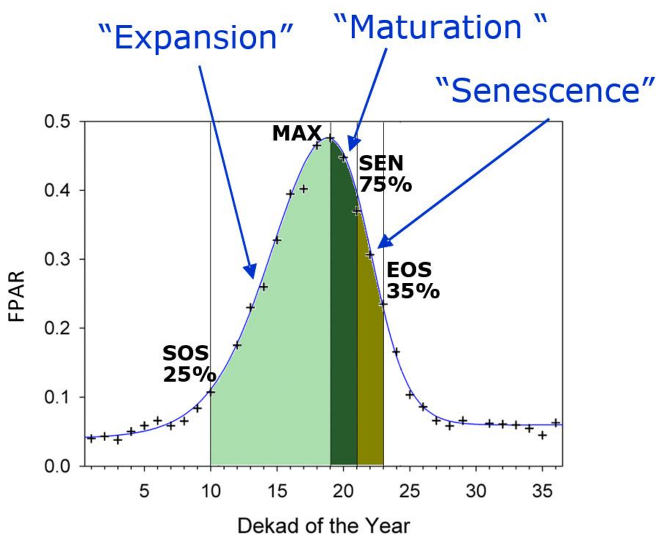
The ASAP systems works with anomaly indicators reported in Table 1. However, an anomaly is relevant only in specific conditions. Being interested in crops, we consider anomalies of remote sensing indicators (e.g. FPAR) only where and when crops grow.

As mentioned, our analysis is restricted to cropland and rangeland areas using the appropriate masks (i.e. where they grow). In addition, only anomalies occurring during the growing season are considered (i.e. when crops and rangelands grow). In fact, for instance, an FPAR anomaly during the winter dormancy of vegetation or in the period when fields are ploughed and bare soil exposed, carries little information. This is why we are interested in defining when vegetation grows.

To define the mean (climatological) growing season period we use the satellite-derived phenology computed with the SPIRITS software (Eerens et al., 2014) on the long term average of MODIS FPAR time series (average yearly temporal evolution computed over the period 2002-2020). The software uses an approach based on thresholds on the green-up and decay phases as described in White et al. (1997).

As a result of the phenological analysis, the following key parameters are defined for each land pixel: number of growing season(s) per year (i.e. one or two); start of season (SOS, occurring at the time at which FPAR exceeds 25% of the ascending amplitude); time of maximum FPAR; start of senescence period (SEN, when FPAR drops below 75% of the descending amplitude); and end of the season (EOS, when FPAR drops below 35% of the descending amplitude). Figure 3 provides a graphical representation of the phenological events and stages.

Figure 3. Graphical representation of the phenological events as derived by satellite data. Dekad stands for 10-day period. The period between SOS and MAX is referred to as "expansion", the one between MAX and SEN as "maturation", and the one between SEN and EOS as "senescence".



Source: JRC

Besides defining the period of vegetation growth, the phenological information provides two phenological indicators that are then used in the classification: the progress of the season and the phenological stage.

The progress of the season is expressed as percentage and represents the fraction of the length of the growing season that has been experienced at time of analysis. A progress of 50% thus indicates that at the time of analysis, the pixel is half-way through the season. The phenological stage refers to the temporal location of the time of analysis within the succession of phenological events. The period between SOS and MAX is referred to as stage "expansion", the one between MAX and SEN as "maturation", and the one between SEN and EOS as "senescence".

3.1.2 Computation of indicators for the classification

The warning classification builds on anomaly indicators of WSI, RFE and FPAR products. All anomalies are expressed as standardized anomalies.

3.1.2.1 WSI

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 computation is described in detail in the WSI technical report available in the info download page[6]. The WSI has been updated for v.8.0 increased spatial resolution and new phenology.

Theoretical considerations and preliminary analysis of WSI distribution per-pixel and -dekad showed that the probability distribution function (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. We thus compute the non parametric non-exceedance probability (NEP, also referred to as the percentile rank).

$$NEP(t) = rank(WSI(t))/(n+1) * 100 \qquad (1)$$

Where WSI(t) is the WSI at time t (in dekads, t = 1, .., 36) and n is the total number of samples (from 1991 to the current year, i.e. 33 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). This relationship is used in ASAP to map NEP values into standard score (zWSI) for comparability with other anomalies.

3.1.2.2 SPI3

RFE data are used to compute the Standardized Precipitation Index (SPI, World Meteorological Organization, 2012), an index widely used to characterise drought at a range of timescales.

The SPI is a probability index that expresses the observed cumulative rainfall for a given time scale (i.e. the period during which precipitation is accumulated) as the standardized departure from the rainfall probability distribution function. The frequency distribution of historic rainfall data for a given pixel and time scale is fitted to a gamma distribution and then transformed into a standard normal distribution. We compute the SPI using data from 1989 to current date and two accumulation periods: one and three months. SPI3 (i.e. using 3 months accumulation period) is

[6] https://agricultural-production-hotspots.ec.europa.eu/documentation.php

considered to account for a prolonged meteorological water shortage and am index of agricultural drought.

3.1.2.3 FPAR

Vegetation biomass anomalies can be assessed by looking at the value of a biophysical variable such as FPAR (or at a biomass proxy such as NDVI) at the time of analysis or at its cumulative value from SOS to the time of analysis. Both approaches have pros and Both approaches have pros and cons as described in Table 2.
In ASAP we do compute both type of anomalies but the classification system uses only the cumulative one.

Table 2. Pros and cons of using a single snapshot of a vegetation index or FPAR at the time of analysis vs. the integrated value from SOS to the time of analysis**.**

	Value at the time of analysis	**Cumulative value from SOS to the time of analysis**
Pros	Quick response in case of abrupt disturbance Easy computation	Reduced sensibility to noise when season progresses More robust to false alarms (anomalous NRT values, typically low because of undetected clouds) Proxy of seasonal productivity (Prince, 1991) Overall view of the season
Cons	Very sensitive to noise in the data (e.g. undetected clouds) Temporal snapshot only	Relatively insensitive to actual disturbances at large progress of season

Source: JRC

Two FPAR-based anomalies are computed over the growing season:

- zFPARc, the standardized score of the cumulative FPAR (FPARc) over the growing season
- mFPARd, the mean of the difference between FPAR and its long term average (FPARd) over the growing season

The two indicators are defined by the following equations.

$$FPARc(t) = \sum_{SOS}^{t} FPAR(t) \quad (2)$$

$$zFPARc(t) = \frac{FPARc(t) - \mu_{FPARc}(t)}{\sigma_{FPARc}(t)} \quad (3)$$

$$mFPARd(t) = \frac{\sum_{SOS}^{t}\left(FPAR(t) - \mu_{FPAR}(t)\right)}{n} \quad (4)$$

Where t refers the time of analysis (current 10-day period), SOS is the start of season, $\mu_{FPARc}(t)$ and $\sigma_{FPARc}(t)$ are the mean and the standard deviation of FPARc at time t, $\mu_{FPAR}(t)$ is the mean of FPAR at time t, and n is the number of 10-day periods from SOS to t. The values of the means and standard deviation are derived from the multi-annual archive of FPAR observations. This multi-annual archive is used to derive long term statistics includes FPAR data from 2002 to the previous year.

3.1.2.4 Applying thresholds to indicators

To identify the area affected by a severe anomaly, we proceed as follows. Once the images of the three indicators are computed, we produce three Boolean masks indicating per pixel if the indicator value is to be considered “critical”. As the three indicators (zWSI, SPI3, and zFPARc) are all standardized variables, we use a common threshold of -1 (i.e. values smaller than this threshold are considered critical), corresponding to the lowest 16% of observations (under assumption of normal distribution). In this way, each pixel in a given ASAP unit is classified as critical (or not) for zWSI, SPI3 and zPFARc.

In order to avoid flagging as critical vegetated pixels with reduced variability (i.e. small), where a zFPARc smaller than -1 may not represent a problem, we also consider the mean of the difference between FPAR and its long term average over the growing season (mFPARd). Thus, pixels having a zFPARc value smaller than the threshold (i.e. -1) are flagged as critical only if also the following condition holds:

mFPARd / HISTORICAL MEAN(mFPAR) * 100 < -10 [%] (5)

We thus request that the mean difference with the historical FPAR is at least 10% smaller than the historical mean.

In addition to that, we also flag "favourable conditions" in case of large positive anomalies of zFPARc (i.e. > 1) to. Here too, a pixel is flagged only if the condition on mFPARd also holds (eq. 5, with > 10 %).

3.2 ASAP unit classification

The information about the area affected by the various types of critical anomalies is summarised at the ASAP unit level for croplands and rangelands separately. Again for conciseness, for specific examples in the following paragraphs we may refer to cropland only.

3.2.1 Operations in the spatial domain

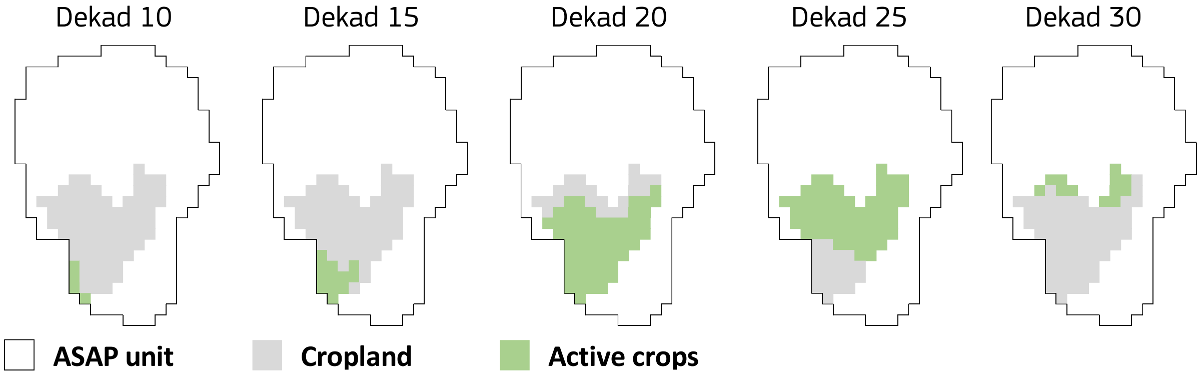
We only consider cropland and rangeland areas, separately. Anomalies occurring outside such target areas are neglected. All subsequent calculations are made on area fraction images (AFI, i.e. the percentage of the pixel area occupied by the given target, ranging from 0 to 100%) to give more weight to pixels with larger cropland percentage. Thus, for instance, the extent of the crop area exceeding a given threshold is not simply the total number of crop pixels but the sum of their AFI values. To ensure consistency between the different resolutions used (500 m FPAR, 0.05° CHIRPS RFE, and 0.25° ECMWF RFE), the coarser resolution data is resampled to the base 500 m grid using nearest neighbour resampling.

3.2.2 Time domain

3.2.2.1 Dynamic masking and active season

The cropland and rangeland AFIs are used to aggregate the values of a given indicator at the ASAP unit level. For instance, if we are interested in retrieving the mean cropland FPAR value for a given ASAP unit, we may compute the weighted mean of FPAR over the pixels belonging the cropland AFI at each date (dekad). The weighting factor will be the AFI value of each single pixel involved in the calculation. However, in this way we would consider all the crop pixels, regardless of the time of analysis *t*. This implies that we may consider the FPAR value of pixels that are located in an area used for crop production also outside the crop growing periods. To avoid such simplification we use the phenology information described in section 3.1.1. Although we use static cropland and rangeland AFIs as base layers, we "switch on and off" the property of being an active crop (or a rangeland) at the pixel level according to the pixel mean phenology. In this way we obtain 36 dynamic crop masks, one per each dekad of the year, indicating per-pixel the presence of crop (or rangeland) in its growing season. A toy example of the evolution of pseudo-dynamic masks is provided in Figure **4**.

Figure 4. Graphical representation of dynamic crop masking. The panels show the static crop mask in grey and the temporal evolution of the pixels being labelled as active crop by the pseudo-dynamic masks at selected dekads.



Source: JRC

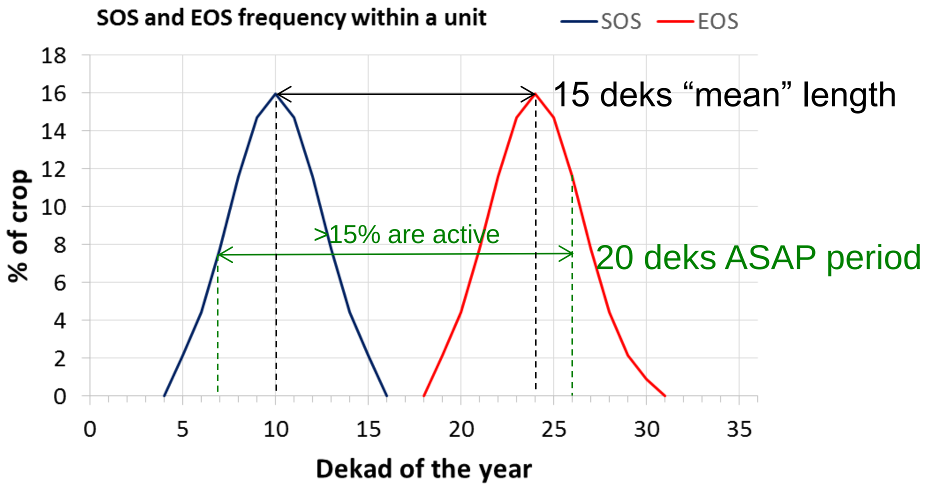
For a given ASAP and time *t* of analysis, the classification is started only when the time *t* is within the (mean) growing season for at least 15% of the total crop area (dekad 15 in Figure **4**).

For the whole period(s) for which active pixels cover a fraction of more than 15% of the cropland area, the unit is considered active. Anomalies occurring outside these periods (i.e. outside the main growing seasons) are not considered by the warning classification system.

It is noted that the active period of an administrative unit may be perceived to be longer than “expected” (i.e. than the active period of a single field). The origin of this effect is explained in Source: JRC

 (based on synthetic data). Despite the fact that the mean season length is 15 dekads (the active period “expected” by the analyst), there is variability in SOS (and hence in EOS). As a results, 15% of the areas is active for a periods of 20 dekads.

Figure 5. Frequency histogram of SOS and EOS for a hypothetical unit shown to explain the active period.



Source: JRC

Finally, the presence of multiple growing seasons (e.g. winter and spring or summer crops) within the solar year inside the unit or even the pixel (discussed in Section 3.2.2.2) may further increase the active period.

3.2.2.2 Unit level progress of the season and phenological stage

Mono- and bi-modal seasons (i.e. one and two growing cycles per solar year) may be present within the administrative unit. Although a dominance of one of the two modalities may be expected (the climate allows for either one or two cycles), it cannot be excluded that, particularly for large ASAP level 1 units, both modalities can be present at the same time.

As a reference for the entire unit we compute the median progress of the season of the administrative unit and the modal phenological stage (expansion, maturation and senescence). So, albeit two seasons with different modality may be present at the same time and with different progress (e.g. the mono-modal in maturation and the bi-modal in expansion), we report the median progress (in %) and modal phenological stage of the active cropland pixels. This information will be thus related to most represented (in terms of area of active pixels) of the two. Where we have two modalities, this “merging” of the two modalities was conceived in order to avoid treating mono- and bi-modal pixels separately, as it would result in having 4 targets by administrative unit, cropland/rangeland x mono-/bi-modal.

The warning level depends on the unit level phenological stage. In fact, during senescence, rainfall based indicators are not considered and only FPAR is used, as rainfall deficit has little importance on crops during this phenological stage (although too much rainfall could cause grain quality issues due to high moisture). In addition, a cumulative FPAR trigger during senescence is not a warning anymore, it is an ascertainment of a season failure that consequently trigger a higher level warning. Note that to determine the modal stage, the mode is computed between the number of pixels in senescence and the one in phenological stages expansion and maturation, together.

3.2.3 Determination of critical area fraction by indicator

The warning level is based on the fraction of the active cropland area (i.e. of cropland pixels having an ongoing growing season) being critical for the three indicators (i.e. for which zWSI, SPI3, and zFPARc are below -1).

In this way we aim at detecting unfavourable growing conditions that may represent a food security problem. We thus trigger a warning only if two conditions on the anomaly are met: 1) the interested area is subjected to a severe negative anomaly of one or more indicators and 2) the area concerned by the anomaly is relevant.

It is noted that if we would take the overall mean of the anomaly, we would instead mix the two components. For instance, a negative anomaly affecting 30% when the other 70% is rather positive, would result in a "normal" average.

We thus compute the critical area fraction (CAF) as the area flagged as critical over the total active area (i.e. cropland pixels with an active growing season at time of analysis):

$$CAF_x = \text{critical\_area}_x / \text{active\_area} \qquad (6)$$

The subscript *x* refers to the indicator considered (*x* = zWSI, SPI3, zFPARc). Note that all calculations are made taking the AFI into account.

3.2.4 Determination of favourable area fraction for zFPARc

As a positive anomaly in zFPARc is univocally interpretable as favourable growth, we keep track of this possible event. In a similar way to the CAF computation described in the previous section, we also compute a favourable area fraction for zFPARc only, i.e. the area subjected to a large zFPARc positive anomaly (as defined in Section 3.1.2.4) divided by the total active area.

3.2.5 Warning level definition

A CAF_x > 25% (i.e. one quarter of the active area) will trigger a warning for that ASAP unit. In order to avoid triggering a warning when CAF is above the 25 % threshold but represents only a small absolute area or a very small fraction of the total area we do not analyse the units meeting the specific criteria described in 2.1.2. Table 3 summarizes all the thresholds used in the warning classification system.

Table 3. List of variables and thresholds used by the warning classification system.

Name	Units	Meaning	Function	Value
Pixel-level settings. Parameters used in the computation of the pixel-based phenology				
SOS_fract	[-]	The season starts when the FPAR profile crosses this fraction of the amplitude in the growing phase	Determine pheno events. The current set of phenology related threshold values was empirically determined with a trial and error process.	0.25
EOS_fract	[-]	Season ends at this fraction in the decay phase		0.35
SEN_fract	[-]	The senescence period starts at this fraction in the decay phase		0.75
Pixel-level settings. Thresholds used to label a pixel as "critical" or "favourable" on the basis of the value (original value and standardized value) of the selected indicator. SD stands for standard deviation.				
CT_zFPARc	SD	Detection of anomalous negative condition	Below this threshold the pixel is flagged as "critical" for zFPARc (standardised cumulative FPAR over the season)	< -1
CT_mFPARd	%	Detection of anomalous negative condition	Below this threshold of the ratio mFPARd / HISTORICAL MEAN(mFPAR) * 100, the pixel flagged as "critical" for mFPARd	<-10%

FT_zFPARc	SD	Detection of anomalous positive condition	Above this threshold the pixel flagged as "favourable" for zFPARs	> 1
FT_mFPARd	%	Detection of anomalous positive condition	Above this threshold of the ratio mFPARd / HOSTIRICAL MEAN(mFPAR) * 100 , the pixel flagged as "favourable" for mFPARd	> 10%
CT_SPI	SD	Detection of anomalous negative precipitation	Below this threshold the pixel flagged as "critical" for SPI3 (Standardized Precipitation Index)	< 1
Administrative unit level settings. Thresholds on the fraction of the total and of the active area. They are used to determine the warning classification and to define the Critical Area Fractions.				
RUN_ACT_PC	%	Percent of active pixels with respect to total (crop or rangeland mask ∩ active area from average phenology)	Above this fraction of active pixels, the warning classification is performed	> 15%
CAFT1, CAFT2, CAFT3	%	Percent of active pixels labelled as "critical" over the total active pixels for indicators zFPARc, zWSI, and SPI3	Trigger a warning level 1 to 4	> 25%
MTATG0	km^2	Minimum total cropland [rangeland] area at GAUL0 level	The unit is not analysed for crops [rangeland] if the total cropland [rangeland] area at the GAUL 0 level is below this threshold	1000
MTAT	km^2	Minimum total cropland [rangeland] area	The unit is not analysed for crops [rangeland] if the total cropland [rangeland] area is below this threshold	25
MTAT%	%	Minimum cropland [rangeland] area fraction (cropland [rangeland] area/total area * 100)	The unit is not analysed for crops [rangeland] if the cropland [rangeland] fraction is below this threshold	0.25%
CED	Cattle units km^{-2}	Minimum cattle equivalent density	The unit is not analysed for rangeland if the cattle equivalent density is below this threshold	0.5

Source: JRC

The level of the final warning depends on the indicator(s) having a CAF exceeding 25% of the cropland / rangeland area and on the modal phenological stage of the crop in the administrative unit. To establish the final warning level, in our classification scheme we put emphasis on the relative importance of the various indicators and their agreement. As we focus on rainfed agriculture, we acknowledge that rainfall is the main driver of crop and rangeland development and that FPAR is the result of vegetation growth under such a driver (plus other perils other than drought), so we rank the water-related and FPAR anomaly events with increasing warning level (Table 4).

Table 4. ASAP warning levels as a function of the warning source (i.e. indicator with Critical Area Fraction, CAF, exceeding the 25% threshold) and phenological phase at which the warning occurs. Note that at the pixel level a critical zFPARc is counted only if also mFPARd is critical.

		Indicator with CAF>25%	Phenological phase: Expansion, maturation	Phenological phase: Senescence
Water deficit possibly evolving into poor growth				
Meteo-based	Water-balance	zWSI	1	-
	Rainfall	SPI3		
		zWSI SPI3	1+	-
Evidence of poor growth				
FPAR-based		zFPARc	2	4
Poor growth & negative prospects				
Meteo & FPAR		zWSI zFPARc	3	4
		SPI3 zFPARc		
		zWSI SPI3 zFPARc	3+	4

- No warning
- Not active
- Water balance
- Biomass
- Water balance + biomass
- End of season biomass

Source: JRC

Levels 1 and 1+ are derived from meteo-based indicators (zWSI and SPI3). The lowest level in this group (level 1) is triggered by a single meteo-based indicator (zWSI or SPI3) while the higher level (1+) is assigned to the co-occurrence of the two conditions: a three-month rainfall deficit (SPI3) that is confirmed by the soil water balance model (zWSI).

Warning level (2) corresponds to a deficit of green biomass (indicated by a low zFPARc), regardless of the causes of this deficit (e.g. rainfall deficit, delayed sowing, fire…).

It is recalled here that, as mentioned in Section 3.1.2.4, a critical zFPARc is counted at the pixel level only if also mFPARd is critical.

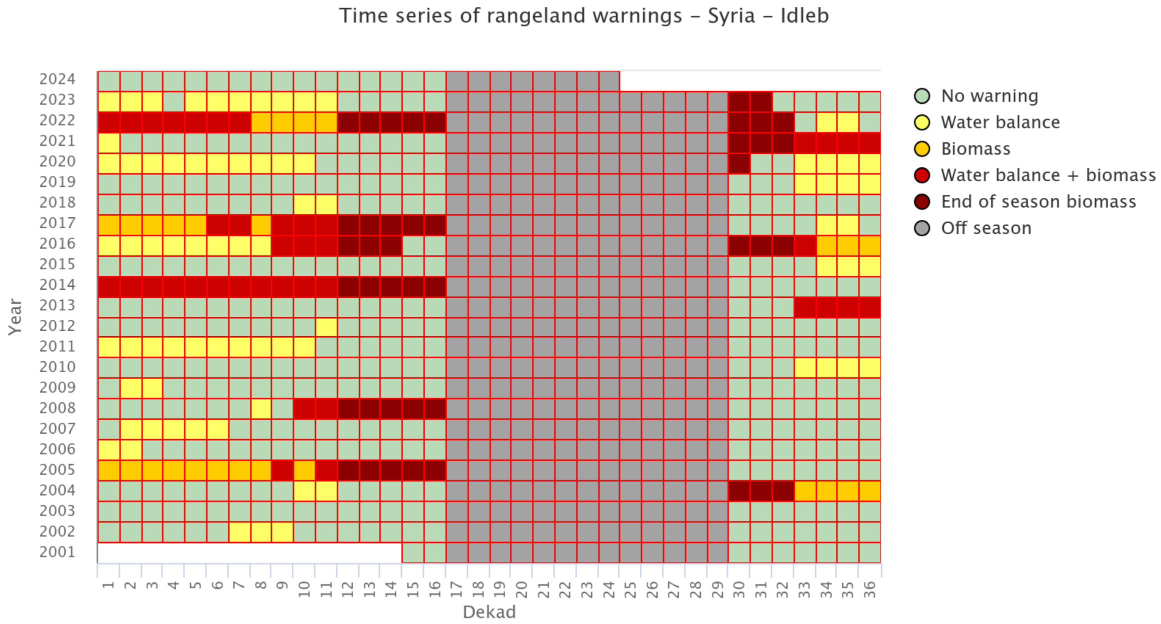
The level 3 (3 and 3+) is assigned to the co-occurrence of FPAR- and meteo-based indicators with a similar logic that was used for the sub-levels of level 1 group. Here the convergence of evidences provided by meteo-indicators and FPAR leads to level 3+.

The occurrence of a positive anomaly of zFPARc is also represented in ASAP. As such occurrence does not represent a deficit, no numeric warning level is assigned to it and the event is simply labelled as “favourable conditions”. It is noted that the same ASAP unit may present simultaneously a “favourable condition” and a warning originating from different indicators or areas.

Finally, phenology is taken into account as during senescence rainfall-based indicators are not considered. Only FPAR is used because we consider that rainfall deficit has little importance on crops during this phenological stage (actually excess rainfall, which is accounted for, could degrade grain quality).

Additional valuable information (namely more trust on a warning level) may be extracted from the analysis of the evolution of the warning level in the preceding dekads. For instance, a persistency of water stress (level 1 warning) for some dekads may be regarded as more reliable than a first appearance of that warning level for the current dekad. Also a level 1 warning preceding a level 2 or 3 warning is likely to indicate an impact of water stress on vegetation biomass while a single biomass warning could be due to delayed vegetation growth (e.g. as a result of late sowings). A level 4 warning (i.e. poor biomass during senescence) preceded by level 2 or 3 warnings in the previous dekads is also more reliable. In order to facilitate such analysis, when a warning is triggered, a matrix showing the temporal evolution of past warnings is produced (see example in Figure 6).

Figure 6. Example of historical warning matrix. Colour coding as in Table 4.

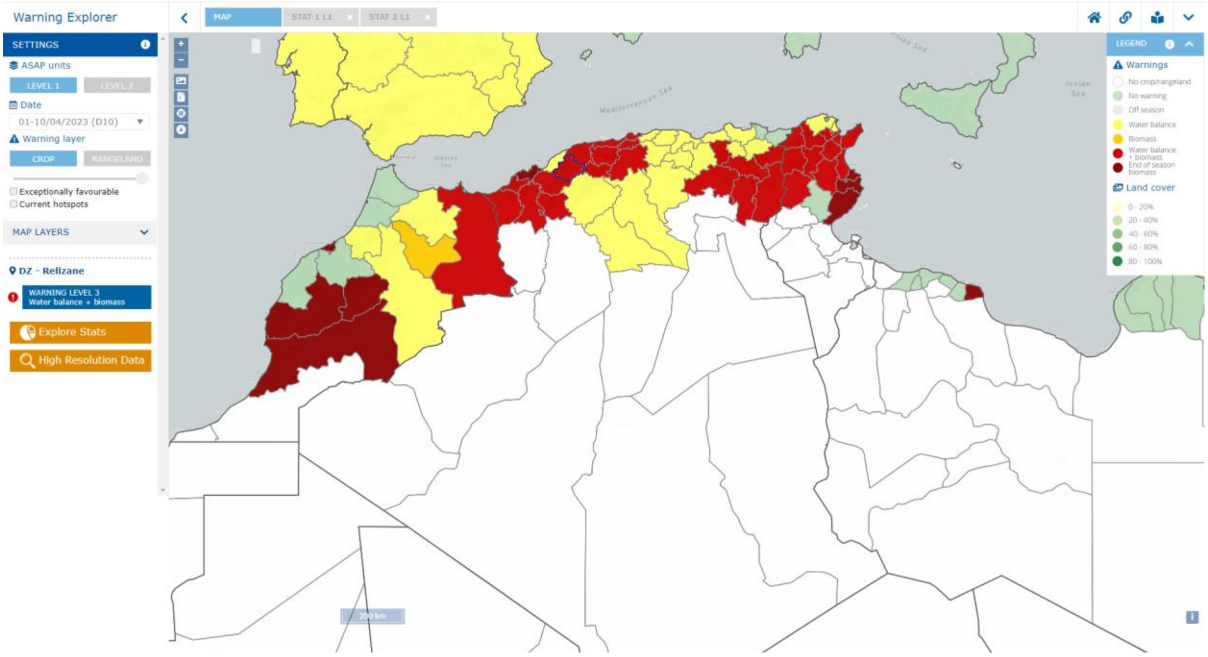


Source: JRC

4 Warning Explorer example

An example of the result of the warning classification system taken from the ASAP Warning Explorer is presented in Figure 7 for the time of analysis (end of dekad 1 of April 2023). ASAP units showing various warning levels are visible in northern Africa, which was affected by a prolonged rainfall deficit.

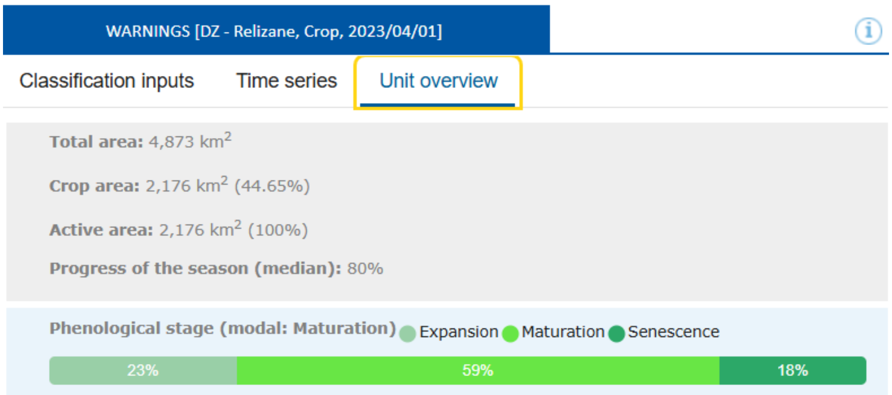
Figure 7. Example of warning classification referring to the time of analysis 11/04/2023, zoom over northern Africa.



Source: JRC

Figure 9 below shows an example of level 1 warning in Algeria (ASAP unit Relizane). At the time of analysis 100% of the crop area was active (see Figure 8), 59% of the active crops were in the phenological stage of “maturation” with a median progress of the season for the unit of 80%. The critical areas concerned by zFPARc (“poor vegetation”) and zWSI (‘sever water deficit’) are above the 25% threshold, which triggers a level 3 warning.

Figure 8. Relizane unit overview at dekad 10 (of 2023)



Source: JRC

Figure 9. Example of a warning level 3 for crops. The top-left panel shows in red the critical area fraction for zFPARc ("poor vegetation"), zWSI ("severe water deficit"), SPI3 ("poor rain (last 90d)"), and in green the favourable area fraction ("abundant vegetation"). Top-right panel shows the share of active area by z-score ranges of selected indicators. Bottom-left panel shows the temporal evolution of FPAR and rainfall (cumulative value over a 10-day period). Bottom-right panel shows the share of active area by progress of the season. Various other graphs and info can be inspected by clicking on panel tabs.

Source: JRC

For more information on this specific drought event please see the ASAP special focus report (https://agricultural-production-hotspots.ec.europa.eu/files/special_focus_2023_05.pdf).

5 Conclusions

The classification system of ASAP automatizes the basic analysis of WSI, rainfall and FPAR data, with the goal of spotting - and highlighting to analysts - critical situations for crop and rangeland growth and highlighting them to analysts.

The ASAP early warning system is currently fully operational and publicly available at https://agricultural-production-hotspots.ec.europa.eu. Every 10 days, ASAP computes the warning level for each ASAP unit and shows these warnings in the "Warning Explorer" web GIS (https://agricultural-production-hotspots.ec.europa.eu/wexplorer/). Then, every month (between the 22nd and the end of the month) and for about 80 food insecure countries, ASAP analysts analyse these warnings to identify countries at risk of food insecurity (the so-called "hotspot" countries).

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List of abbreviations and definitions

Abbreviations	Definitions
AFI	Area Fraction Image
AMIS	Agricultural Market Information System
ASAP	Anomaly Hot Spot of Agricultural Production
CAF	Critical Area Fraction
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CM4EW	Crop Monitoring for Early Warning
DG DEVCO	Directorate General for International Cooperation and Development
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EOS	End of Season
GAUL	Global Administrative Unit Layer
GEO	Group on Earth observations
GEOGLAM	Global Agriculture Monitoring Initiative
GIS	Geographic Information System
JRC	Joint Research Centre
LST	Land Surface Temperature
NDVI	Normalized Difference Vegetation Index
RFE	Rainfall Estimates
SD	Standard Deviation
SOS	Start of Season
SPI	Standardized Precipitation Index

Abbreviations	Definitions
SPIRITS	Software for Processing and Interpreting Remote sensing Image Time Series
WSI	Water Satisfaction Index

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Annexes

Annex 1. Change record

Version	Date	Description of main changes
1.1	20/12/2016	First public version
2.0	18/10/2017	• Change in remote sensing data source, from MetOp to filtered MODIS. • Update of crop and rangeland masks
2.1	09/04/2018	• Modification of supplementary condition to flag zNDVIc as "critical". From (mNDVId < -0.05) to (mNDVId / HISTORICAL MEAN(mNDVI) * 100 < -10 %)
2.2	20/04/2018	• Inclusion of an additional condition for the exclusion of the rangeland target in specific units, i.e. besides minimum rangeland area, also minimum density of livestock equivalent units
3.0	14/03/2019	• Use of the water satisfaction index instead of SPI1 in the computation of warnings
4.0	08/07/2019	• CHIRPS rainfall data used instead of ECMWF rainfall data between 50° N and 50° S. Affected indicators: SPIs, WSI. CHIRPS data are provided globally between 50° N and 50° S. Outside this latitude band, ECMWF rainfall data are used. • Simplification of the warning classes
5.0	25/04/2020	• Redesign of the High Resolution Viewer
5.1 to 6.3.1	2021-2022	• Minor and patch releases, removal of exclusion of water-based indicator in non water-limited countries
7.0	17/7/2023	• Implementation of ASAP level 2 units
8.0.0	15/07/2024	• Improved biomass proxy indicator (from 1km NDVI to 500m FPAR), updated phenology and improved crop and rangeland masks, update of Water Satisfaction Index to increase spatial resolution and new phenology

More information about changes and minor patches can be found at https://agricultural-production-hotspots.ec.europa.eu/changelog.php.

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