

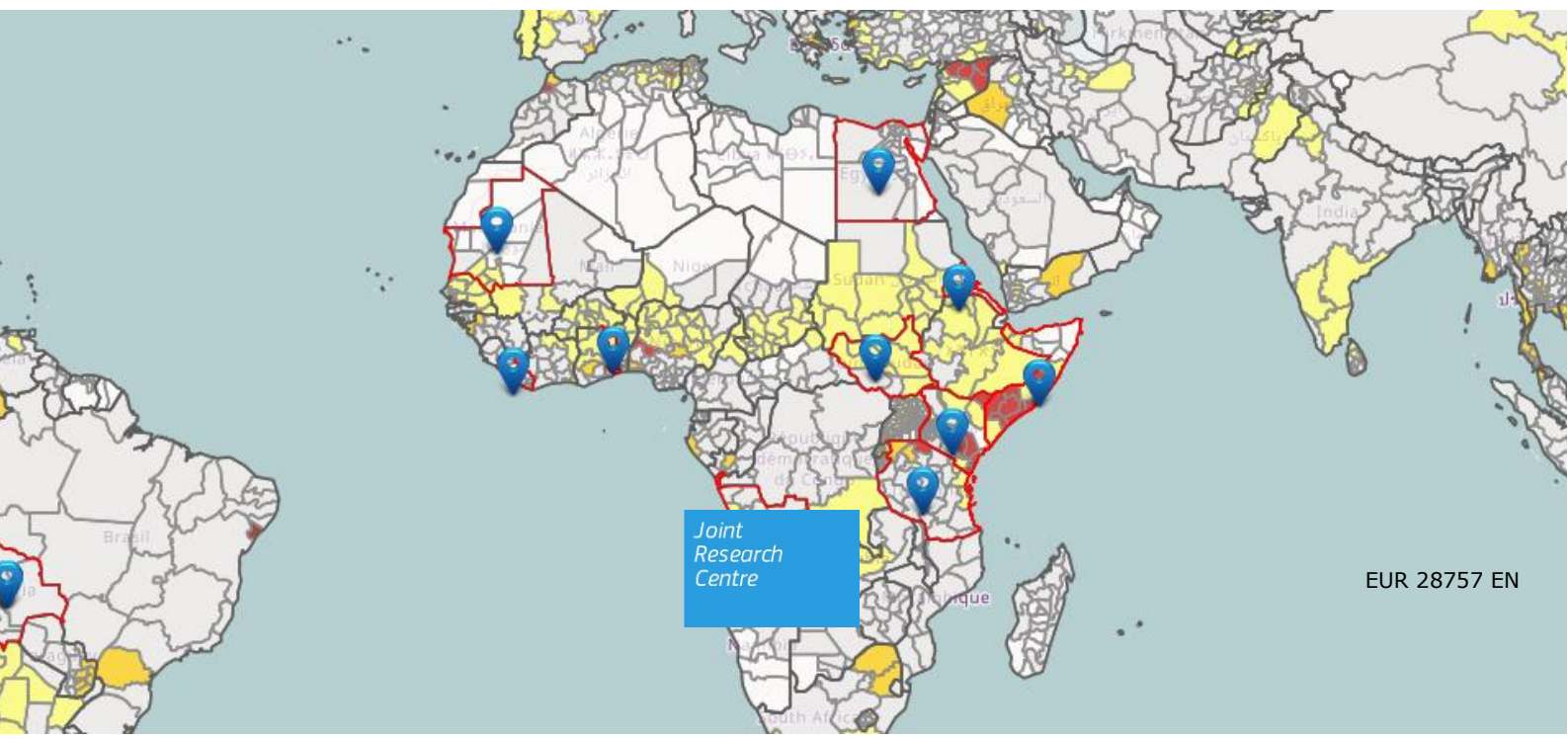
JRC TECHNICAL REPORTS

The warning classification scheme of ASAP – Anomaly hot Spots of Agricultural Production, v4.0

*Technical description of
warning classification
system version 4.0*

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2019



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JRC Science Hub

<https://ec.europa.eu/jrc>

JRC107892

EUR 28757 EN

ISBN 978-92-79-73183-9

ISSN 1831-9424

doi:10.2760/798528

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How to cite: Meroni M., Rembold F., Urbano, F., Csak G., Lemoine G., Kerdiles H., Perez-Hoyoz A. (2019). The warning classification scheme of ASAP – Anomaly hot Spots of Agricultural Production, v4.0, doi:10.2760/798528

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Change record

Version	Date	Description of main changes
1.1	20/12/2016	First public version
2.0	18/10/2017	<ul style="list-style-type: none">• Change in remote sensing data source, from MetOp to filtered MODIS.• Update of crop and rangeland masks
2.1	09/04/2018	<ul style="list-style-type: none">• Modification of supplementary condition to flag zNDVIc as “critical”. From (mNDVI_d < -0.05) to (mNDVI_d / HISTORICAL MEAN(mNDVI) * 100 < -10 %)
2.2	20/04/2018	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• Use of the water satisfaction index instead of SPI1 in the computation of warnings
4.0	08/07/2019	<ul style="list-style-type: none">• 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

Summary

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 crop and vegetation 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 the United Nation Sustainable Development Goal 2 related monitoring, remains challenging.

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

The first step is fully automated and aims at classifying each sub-national administrative unit (mostly Gaul 1 level, i.e. first sub-national level) into a set of possible warning levels, ranging from “none” to level 4. Warnings are triggered only during the crop growing season, as derived from a remote sensing based phenology. The classification system takes into consideration the fraction of the agricultural land for each unit that is affected by a severe anomaly of a soil water balance (the Water Satisfaction Index, WSI), a rainfall-

based indicator of meteorological drought (the Standardized Precipitation Index computed at the 3-month scale, SPI3), a biophysical indicator (the anomaly of the cumulative Normalized Difference Vegetation Index from the start of the growing season, NDVIc), and the timing during the growing cycle at which the anomaly occurs. 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 agricultural area affected. Maps and summary information are published in the Warning Explorer available at <https://mars.jrc.ec.europa.eu/asap/wexplorer/>.

The second step, not described in this manuscript, 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".

This report focusses on the technical description of the automatic warning classification scheme version 4.0.

1 Introduction

Agricultural drought, with its negative effects on agricultural production, is one of the main causes of food insecurity worldwide. Extreme droughts like those that hit the Sahel region in the 70's and 80's, the Ethiopian drought in 1984 and the recent Horn of Africa drought in 2010/2011 have received extensive media attention because they directly caused hunger and death of hundreds of thousands of people (Checchi and Robinson, 2013). With the increased food prices in the first decade of the century (more than doubled according to Food and Agricultural Organization Food Price Index) and a continuously increasing demand for agricultural production to satisfy the food needs and dietary preferences of an increasing world population, drought is one of the climate events with the highest potential of negative impact on food availability and societal development. Droughts aggravate the competition and conflicts for natural resources in those areas where water is already a limiting factor for agriculture, pastoralism and human health. Climate change may further deteriorate this picture by increasing drought frequency and extent in many regions of the world due to the projected increased aridity in the next decades (IPCC, 2013).

Crop failures and pasture 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 the impact of a drought can be timely assessed, 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 remote sensing derived 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 how important it is to dispose of global early warning system. Finally the JRC is getting progressively more involved in global multi-agency networks for agricultural monitoring such as for example the Global Agriculture Monitoring Initiative (GEOGLAM), promoted by the G20 international forum as part of 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 food 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 Cooperation and Development (DG DEVCO) 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 the information system ASAP (Anomaly hot Spots of Agricultural Production). ASAP addresses users with no expertise in processing remote sensing and weather data for crop monitoring and aims at

directly providing them with timely and concise decision support messages about agricultural drought dependent production anomalies.

With ASAP we propose a two-step analysis to provide timely warning of possible production deficits in water-limited agricultural systems worldwide every month.

The first step is described in this report and consists in an automatic warning classification system aimed at supporting the analysts in their assessment at country level.

The goal of the warning classification algorithm is to produce a reliable warning of possible agricultural production deficit at the level of administrative units (mostly represented by the first subnational administrative level, GAUL1), with a homogeneous approach at the global scale. This is achieved performing an automatic standard analysis of rainfall estimates and remotely sensed 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 none to 4. The system is mainly based on the time series analysis software SPIRITS (Software for Processing and Interpreting Remote sensing Image Time Series; Eerens et al., 2014) developed by the Flemish Institute for Technological Research (VITO) and JRC.

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 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 contribution we describe the main features of the ASAP warning classification system version 4.0, publicly available at <https://mars.jrc.ec.europa.eu/asap/wexplorer/>. Section 2 describes the spatial framework at which the classification system works. Section 3 lists the base information layer used for the classification. The method used is 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). Conclusions are drawn in Section 5 whereas near-future and long-term improvements of the classification methods are outlined in Section 6.

2 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, FAPAR; the Leaf Area Index, LAI). Such products are mainly derived from space measurements 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 often 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 typically requires a number of processing steps that include the temporal smoothing of the cloud-affected remote sensing signal, 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 the LTA.

The automatic warning classification of ASAP v4.0 is based on:

- 10-day estimates of the Water Satisfaction Index (WSI), an indicator of crop (or rangeland) performances based on the availability of water to the crop during the growing season at 1 km spatial resolution (spatial resolution of meteo data depending on meteo variable and latitude, details below).
- 10-day rainfall estimate (RFE) products provided by: i) the European Centre for Medium-Range Weather Forecasts (ECMWF) at 0.25° spatial resolution; ii) the Climate Hazards Group (CHIRPS product) at 0.05° spatial resolution.
- 10-day composite of the Normalized Difference Vegetation Index (NDVI) from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument at 1 km spatial resolution.

WSI is described in detail in Boogaard et al. (2019), available here: <https://mars.jrc.ec.europa.eu/asap/files/WSI%20TECH%20REP.pdf>. 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.

ECMWF weather data are retrieved from the ECMWF forecasting system. The time series of ERA-Interim reanalysis model is used for the period spanning from 1989 up to current year-1. Era-Interim variables are produced at 6-hourly time-step at a spatial resolution of approximately 80 km. Data from 2016 up to the time of analysis are from the deterministic forecast model (HRES), originally produced at 3-hourly time-step with about 9 km spatial resolution (ECMWF, 2015). While HRES forecasts are produced for the next 10 days, only the forecasts for the first day are retained here. After computation of daily values, both products are then scaled to a reference grid with 0.25° resolution. Daily data of precipitation and evapotranspiration are temporally aggregated to a 10-day frequency using the cumulative value.

CHIRPS 2.0 dekadal data at 0.05° spatial resolution are downloaded from the Climate Hazards Group ftp site¹. 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.

CHIRPS, ECMWF and MODIS time series are available from years 1981, 1989² and 2002, respectively. Satellite-based phenology is computed over a 15-year time series (2002-2016) of MODIS NDVI observations.

Filtered MODIS NDVI for optimal noise removal

We use the MODIS data processing developed by Klisch and Atzberger (2016) applied to MOD13A2 and MYD13A2 V006 16-day Global data at 1 km resolution and provided by the Institute of Surveying, Remote Sensing and Land Information, BOKU University, Wien, Austria.

The objective of the processing is the production of quality improved (noise-removed and gap-filled) NDVI data for both the archive (past observations) and

¹ <ftp://chg-ftpout.geog.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/>

² 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)

near real time (NRT, current observations) of 10-day composite MODIS 1 km NDVI from NASA collection 6. All improved data are produced together with an estimation of their uncertainty.

The processing chain uses MOD13A2 and MYD13A2 collection 6 products of the MODIS Terra and Aqua satellites from LP DAAC (from 2002 onwards). These products are (unfiltered) 16-day NDVI at 1km spatial resolution. The products include quality information and composite day of the year.

The two sensors have different overpass times, hence different sensor zenith angle. It was nevertheless decided to use data from both sensors, as the advantage of having more (valid) observations exceed the cons of having observations, acquired under different view angels.

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

At the start of the processing, the data is smoothed. That means this process is done only once using the entire time series up to the latest point in time where data are available from both previous and later times. 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 (e.g. 2002 to 2016) to daily NDVI values. The smoothing takes into account the quality of the observations according to the MODIS VI Quality Assessment Science Data Set (QA SDS) (Didan et al., 2015) and the compositing day for each pixel. A smoothing parameter of 3000 is applied with three iterations to best fit the upper envelope of the NDVI observations.

Weights are assigned to the MODIS observations based on the QA SDS. From the output of daily NDVI time series, only 10-day (dekadal) images are stored. The 10-day composites have a fixed date for the projection 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 are calculated describing the typical NDVI temporal paths (and intra-annual variabilities) for a given location and time.

The near real-time filtering is executed at the end of each 10-day period (dekad) estimating the state of vegetation coverage (NDVI) 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 filtering. However, a smoothing parameter of 1000 is applied and the output is different. The smoothing parameter of 1000 ensures enough flexibility of the resulting spline. For each filtering step (for each 10-day period), the NRT filtering outputs six images. Filtered NDVI images of the successive dekads are stored ("output 0", consolidation stage 0) but also for the past four dekads, representing different consolidation stages of the filtered NDVI ("output 1" to "output 4"). Obviously, "output 4" (consolidation stage 4) is more reliable (e.g. better constrained through available data) compared to the "output 0" which is always extrapolated as (reliable) MODIS observations become available only after some days.

The sixth and final image stored every dekad corresponds to the fully consolidated NDVI. Understandably, this fully smoothed value will become available only after 3 months (9 dekads) but has the advantage of observations available to the left and right (e.g. back and forward in time). Hence, this output is of highest quality. It is delivered for the archived and NRT data. In BOKU's processing, it serves as a "reference" for modelling the uncertainty.

3 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 the given target, either cropland or rangeland, ranging from 0 to 100%).

The cropland and rangeland masks were derived by combining different land cover datasets into an optimal one.

In the translation of the legends of the various datasets we adopted the following definitions of croplands and rangelands. Cropland is defined as the land used for cultivation of crops, encompassing both total areas under arable land and permanent crops. Grassland is defined according to FAO-GLCshare (Latham *et al.*, 2014). Thus, grasslands included 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 with cover was less than 10%.

In Africa, the land cover hybridization relied on a multi criteria analysis (MCA) that evaluated eight global datasets (i.e. CGLS-LC100 v1.0, GLC2000, GLCNMO v2, GlobCover 2009, Globeland30, LC-CCI 2015, MODISLC 2010, S2 Prototype Land Cover) and 16 regional land cover datasets (Pérez-Hoyos *et al.*, 2017a). All the datasets were evaluated and weighted at country-level according to the following five criteria: timeliness, spatial resolution, comparison of total area with FAOSTAT statistics, accuracy assessment and expert knowledge. Figure 1 shows the resulting data set selection.

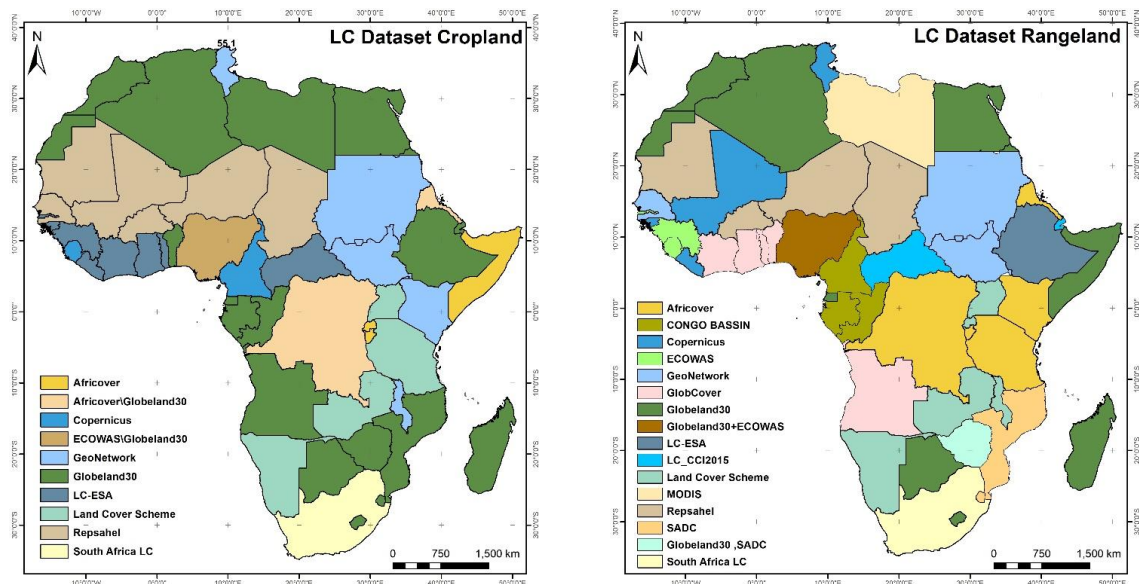


Figure 1. Dataset selected for the cropland (left) and rangeland mask (right) from the multi-criteria analysis.

Bangladesh, Indonesia, Laos, Myanmar, Thailand, Timor-Leste, Philippines and Vietnam datasets were selected based on a comparison of eight global land cover datasets using

accuracy assessment and agreement with FAO statistics as criteria (Pérez-Hoyos et al., 2017b).

For the rest of countries, priority was given to the regional dataset. For the countries where we could not find a suitable dataset (either for both croplands and rangelands or for one of them), the global land cover dataset with the highest spatial resolution was investigated through visual inspection supported by Google Earth high-resolution imagery. If the reliability of the high resolution dataset was qualitatively found not realistic in the comparison with high-resolution imagery, the FAO-GLCshare was finally selected (Table 1).

Table 1. Dataset selected for the cropland and rangeland mask based on comparison with Google Earth high-resolution imagery.

Country	Cropland	Rangeland
AMERICA		
Argentina	Cobertura y uso de suelo. INTA 2006-2009. http://www.geointa.inta.gob.ar/2013/05/19/cobertura-del-suelo-de-la-republica-argentina/	FAO-GLCshare Grassland layer with grassland cover fraction >20%
Belize, Dominican Republic, French Guiana, Jamaica, Surinam, Venezuela, Puerto Rico	FAO-GLCshare dominant class per pixel	
Bolivia	Mapa de cobertura y uso actual de la tierra Bolivia 2010. Ministerio de Desarrollo Rural y Tierras. https://geo.gob.bo/geonetwork/	
Brazil	Mapa de Cobertura e Uso da Terra do Brasil. Instituto Brasileiro de Geografia e Estadística 2014. https://www.ibge.gov.br/geociencias-novoportal/informacoes-ambientais/cobertura-e-uso-da-terra/10867-cobertura-e-uso-da-terra.html?=&t=downloads	
Canada	Annual Crop Inventory 2016. Government of Canada 30m (tiff) 2016. http://www.agr.gc.ca/atlas/data_downloads/agr/annualCropInventory/tif/2016/	Commission for Environmental Cooperation, Land Cover 2010, 250 m. http://www.cec.org/tools-and-resources/map-files/land-cover-2010
Chile, Paraguay	FAO-GLCshare dominant	FAO-GLCshare Grassland layer with grassland cover fraction >20%
Colombia	Mapa de cobertura tierra 2010-2012. IDEAM (Sistema de Información Ambiental de Colombia)	
Cuba	LC-CCI 2015	FAO-GLCshare dominant class per pixel
Ecuador	Gobierno de Ecuador, Ministerio de Agricultura y Ganadería 2014. http://geoportal.agricultura.gob.ec/cobertura/	
Guatemala	Bosques y usos de la tierra 2012. Sistema Nacional de Información Territorial. Secretaría Técnica http://ideg.segeplan.gob.gt/geoportal/	
Haiti	Carte du Centre National de l'Information Geo-Spatial. https://www.cnigs.ht/ (provided by the CNIGS)	
Honduras	Cobertura de usos del suelo 2009. Sistema Nacional de Información Territorial. Secretaría Técnica de	FAO-GLCshare dominant class per pixel

	Planificación y Cooperación Externa. http://www.sinit.hn/	
Mexico	Commission for Environmental Cooperation, Land Cover 2010. 250 m. http://www.cec.org/tools-and-resources/map-files/land-cover-2010	Commission for Environmental Cooperation, Land Cover 2010, 250 m. http://www.cec.org/tools-and-resources/map-files/land-cover-2010
Panama	Cobertura Boscosa 2000. http://www.ipde.gob.pa	FAO-GLCshare dominant class per pixel
Peru	Mapa Nacional de Cobertura Vegetal 2015. Ministerio de Medio Ambiental. http://www.geogpsperu.com/2016/06/mapa-de-cobertura-vegetal-actualizado.html	
Uruguay	Cobertura del suelo 2015. Ministerio de Vivienda Ordenamiento Territorial. https://www.dinama.gub.uy/geoservicios/	
USA	National 2016 CLD 30m. Department of Agriculture National Agricultural Statistics Service. https://www.nass.usda.gov/Research_and_Science/Cropland/Release/	Commission for Environmental Cooperation, Land Cover 2010, 250 m. http://www.cec.org/tools-and-resources/map-files/land-cover-2010
EURASIA		
Europe	Corine Land Cover 2012. http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012	
China		Globeland30
India	Land Use/Land Cover. National Remote Sensing Centre 2014.	
Japan	High Resolution Land-Use Land Cover Map, Japan Aerospace Exploration Agency 2006-2011 http://www.gsi.go.jp/kankyochiri/gm_japan_e.html	
Nepal, Bhutan		Land Cover Map of Himalaya Region.2010
Kazakhstan, Mongolia	Globeland 30	FAO-GLCshare Grassland layer with grassland cover fraction >20%
Russia	Terra Norte Arable Land 2014 http://vega.geoglam.ru/download.shtml?lang=eng	FAO-GLCshare dominant class per pixel
OCEANIA		
Australia	Australia Dynamic Land Cover Australia January 2014-December2015. Australian Government. https://ecat.ga.gov.au/geonetwork/srv/eng/search#!19b3b236-e0aa-d2fb-e053-10a3070af790	
New Zealand	LCDB v4.1 Land Cover Database version 4.1 2015. https://iris.scinfo.org.nz/layer/48423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/	
DPRK, Irak, Iran, Israel, Lebanon, Saudi Arabia, Syria, South Korea, Oman, Turkmenistan, Uzbekistan, Yemen, West Bank	Globeland30	FAO-GLCshare dominant class per pixel
China		Globeland30

This process resulted in the production of two hybrid static maps at 250 m, one for cropland and another one for grassland for the nominal year 2016. After that, the datasets were resampled the lower spatial resolution of ASAP (1 km) with both masks expressed

as fraction image (AFI, i.e. the percentage of the pixel area occupied by given target, either cropland or rangeland, ranging from 0 to 100%).

4 Geographic coverage

The automatic warning classification capitalizes on the global availability of the climatic and remote sensing indicators and is produced globally. At the sub-national level all classified warnings are made available in a web-GIS page named "Warning Explorer".

Concerning the final hot spot identification at the national level only, the automatic warning information produced for about 90 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.

4.1 Spatial framework

4.1.1 Spatial unit of analysis

National and sub-national boundaries rely on the Global Administrative Units Layers (GAUL) of the Food and Agriculture Organization of the United Nations. The base layer used by the classification system is the GAUL level 1 representing the first sub-national level administrative units. This level 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). In addition, working with administrative units has the advantage that they are well known and analysts can easily compare with other data normally available at the administrative level (crop types, calendars, area and yield statistics, etc.).

This layer has been adapted to the specific needs of the early warning system to form an ASAP unit, as follows:

- Small GAUL1 units are aggregated at the GAUL0 level (country level). In particular, when the average size of GAUL1 units within a GAUL0 is less than 5000 km², all GAUL1 units are merged together and the GAUL0 polygon is used as the ASAP unit. An exception to this rule is applied in Africa to avoid oversimplification in the main ASAP countries: merging is not applied if the GAUL0 size is greater than 25000 km².
- Suppression/merging of negligibly small ASAP units. All the resulting single polygons with a total area smaller than 200 km² 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).
- For countries of special interest where the resulting units were considered too coarse for crop/rangeland monitoring, specific and more detailed administrative units (GAUL2 or country-specific) were used (e.g. Kenya, Rwanda, Burundi, Haiti, Ethiopia, Namibia).
- Total crop and rangeland areas are calculated per ASAP unit. GAUL0 units with crop/rangeland area < 1000 km² (MTATG0 threshold). ASAP units with

crop/rangeland < 100 km² (MTAT threshold) are excluded. ASAP units are excluded for crops [rangelands] also if the agricultural [rangeland] area is between 100 and 1500 km² (MTAT2 threshold) and the area fraction is smaller than 1 % (MTAT% threshold). 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.

- 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).

4.1.2 Identification of water limited regions

Water, temperature and radiation are the main limiting factors to vegetation growth at the global level (Nemani et al., 2003). All limiting factors are indirectly covered by ASAP that uses NDVI (a spectral vegetation index related to vegetation biomass and health), WSI and rainfall. Temperature is accounted for the WSI while negative NDVI anomalies indicate resulting sub-optimal vegetation growth, independently from limiting factors.

In ASAP we mainly focus on drought-related production deficit. As a consequence, we monitor precipitation in water-limited ecosystems with the aim of anticipating biomass development problems. On the contrary, the interpretation of RFE-based anomalies in non water-limited areas is not straightforward and may be misleading. Therefore, RFE are only used in ASAP in water-limited regions.

As a rough indicator of water-limitation we use the simplified annual climatic water balance, represented by the difference between the mean cumulative annual values of precipitation and potential evapotranspiration (similarly to the aridity index of UNEP; UNEP, 1992). Both precipitation and potential evapotranspiration are from ECMWF. A positive water balance indicates regions where water is not a limiting factor, i.e. the evaporative demand is met by the available water. We thus use both indicators (RFE and NDVI) in countries where the annual climatic water balance (i.e. precipitation – potential evapotranspiration) is negative (Figure 2). Elsewhere, we only consider NDVI.

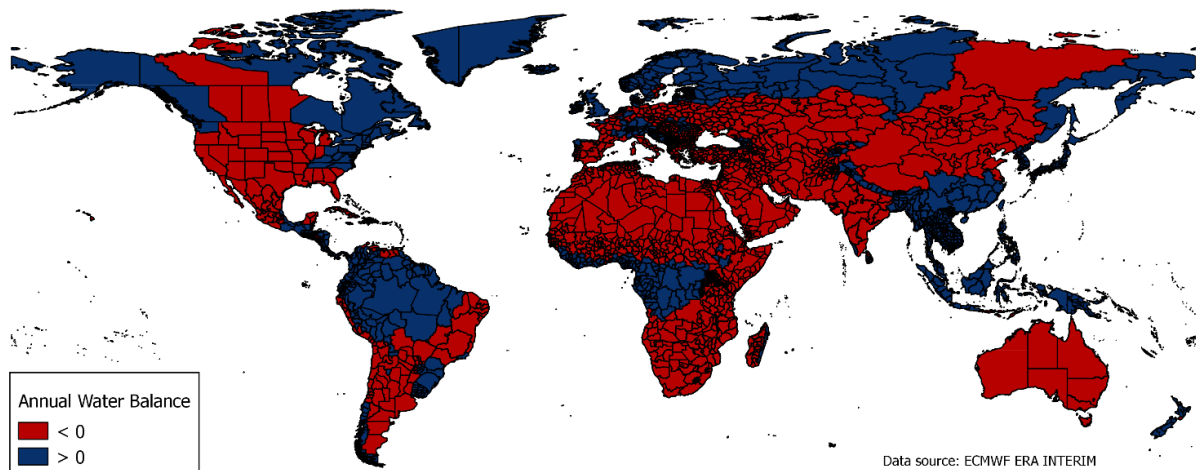


Figure 2. Annual climatic water balance. Data source: 10-day ECMWF ERA-INTERIM rainfall estimates and potential evapotranspiration, average computed over the period 1989-2014.

5 Methods

Although an ideal monitoring system would be crop specific, we recognize that crop specific global maps are not available. In addition, crop specific maps would need to be updated every year as crops location is not constant over time due to rotation practices, for instance. Therefore, our analysis is performed separately for 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 at the adapted GAUL1 level. 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 5.1. Once the pixel-level indicators are computed, they are aggregated at the administrative unit and used in the classification for the warning (Section 5.2)

The ASAP software platform uses a combination of open source tools, mainly PostgreSQL, PostGIS, SPRITS, GLIMPSE, Python, R, Geoserver, and OpenLayers.

5.1 Pixel-level analysis

The main indicators used by the classification system (Table 2) are computed at the pixel level whenever new observations become available (i.e. every 10-days). Indicators rely on the per pixel definition of the multi-annual average of phenology, described in the following section.

Table 2. Indicators used in the warning classification system. Detail in Section 5.1.2.

mNDVI_d	[Anomaly] Mean NDVI 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
zNDVI_c	[Anomaly] Standardized score (Z-score) of the cumulative NDVI over the growing season period experienced until the date requested. It indicates how many standard deviation the cumulative NDVI 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-months 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

5.1.1 Computation of remote sensing phenology

The ASAP systems works with anomalies of NDVI and RFE (Table 2). Different mathematical formulations for the anomalies exists. In general, anomalies are simple statistics describing the departure of the current observation from the observed historical distributions. For instance, the simplest NDVI anomaly for the current 10-day period X is the difference between the current NDVI value and its historical average (i.e. the temporal average of NDVI observed at period X over all the available years present in the archive).

However, an anomaly is relevant only in specific conditions. Being interested in crops, anomalies of remote sensing indicators should be considered 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 retained (i.e. when they grow). In fact, for instance, an NDVI 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 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 NDVI time series (average yearly temporal evolution computed over the period 2002-2016). 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 per year (i.e. one or two); start of season (SOS, occurring at the time at which NDVI grows above the 25% the ascending amplitude); time of maximum NDVI; start of senescence period (SEN, when NDVI drops below 75% of the descending amplitude); and end of the season (EOS, when NDVI drops below 35%). Figure 3 provides a graphical representation of the phenological events.

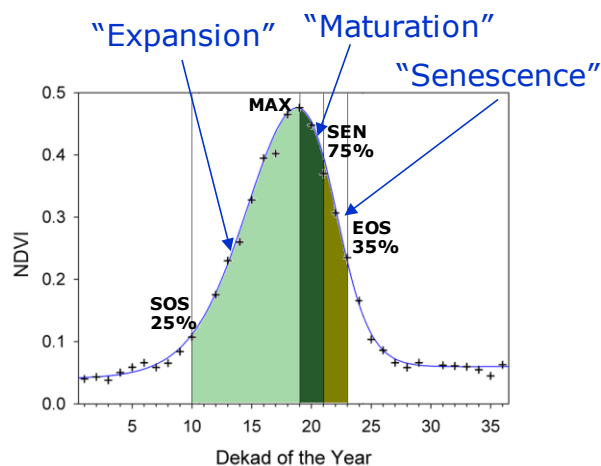


Figure 3. Graphical representation of the phenological events as derived by satellite data. Dekad stands for 10-day period. The period between SOS and MAX is referred to as "expansion", the one between MAX and SEN as "maturation", and the one between SEN and EOS as "senescence".

Besides defining the period of vegetation growth, using the phenological information we retrieve two phenological indicators that are then used in the classification: the progress of the season and 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 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".

5.1.2 Computation of indicators for the classification

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

5.1.2.1 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 Boogaard et al. (2018), available here: <http://h04-tst-asap.jrc.it/asap/documentation.php>.

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. We thus compute the non parametric non-exceedance probability (NEP, also referred to as the percentile rank).

$$NEPd = \text{rank}(WSId)/(n+1) * 100$$

Where WSId 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). This relationship is used in ASAP to map NEP values into standard score (zWSI) for comparability with other anomalies.

5.1.2.2 SPI3

RFE data are used to compute the Standardized Precipitation Index (SPI, World Meteorological Organization, 2012), an index widely used to characterise meteorological 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 computed 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 considered to account for a prolonged meteorological water shortage.

5.1.2.3 NDVI-based

Vegetation anomalies based on biophysical indexes (such as NDVI) can be computed by looking at the value of the index at the time of analysis or at its cumulative value from SOS to time of analysis. Both approaches have pros and cons (

Table 3). In ASAP we do compute both type of anomalies but we restrict the analysis to the cumulative ones in the classification system.

Table 3. Pros and cons of using a single snapshot of a vegetation index at time of analysis vs. integrated value from SOS

	Time of analysis	Cumulative value from SOS
Pros	Quick response in case of abrupt disturbance	Reduced sensibility to noise when season progresses
	Easy computation	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	Quick response to noise	Relatively insensitive to actual disturbances at large progress of season
	Temporal snapshot only	

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

- zNDVI_c, the standardized score of the cumulative NDVI (NDVI_c) over the growing season
- mNDVI_d, the mean of the difference between NDVI and its long term average (NDVI_d) over the growing season

The two indicators are defined by the following equations.

$$NDVI_c(t) = \sum_{SOS}^t NDVI(t) \quad (1)$$

$$zNDVI_c(t) = \frac{NDVI_c(t) - \mu_{NDVI_c}(t)}{\sigma_{NDVI_c}(t)} \quad (2)$$

$$mNDVI_d(t) = \frac{\sum_{SOS}^t (NDVI(t) - \mu_{NDVI}(t))}{n} \quad (3)$$

Where t refers the time of analysis (current 10-day period), SOS is the start of season, $\mu_{NDVI_c}(t)$ and $\sigma_{NDVI_c}(t)$ are the mean and the standard deviation of NDVI_c at time t , $\mu_{NDVI}(t)$ is the mean of NDVI 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 NDVI observations.

5.1.2.4 Applying thresholds to indicators

Being interested in the area that is affected by a severe anomaly, we proceed as follows. Once the images the various 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 zNDVI_c) are all standardized variables, we use a threshold of -1 (i.e. values smaller than this threshold are considered critical), corresponding the lowest 16% of observations (under assumption of normal distribution). In this way, each pixel in a given GAUL1 is classified as critical (or not) for zWSI, SPI3 and zNDVI_c.

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

$$mNDVI_d / \text{HISTORICAL MEAN}(mNDVI) * 100 < -10 \quad [\%] \quad (4)$$

In addition to that, we also consider large positive anomalies of zNDVI_c (i.e. > 1) to flag the pixel as "favourable conditions". Once again, a pixel is flagged only if the condition on mNDVI_d also holds ($mNDVI_d / \text{HISTORICAL MEAN}(mNDVI) * 100 > 10$ [%]).

5.2 Subnational-level 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. For brevity and conciseness, when describing examples in the following, we refer to cropland only.

5.2.1 Operations in the spatial domain

We only consider cropland and rangeland areas, separately. Anomalies occurring outside such targets are neglected. All subsequent calculations are made on area fraction image masks (AFI, i.e. the percentage of the pixel area occupied by the given target, ranging from 0 to 100%). Thus, for instance, the extent of the crop area exceeding a given threshold is not simply the total number of the crop pixels but the sum of their AFIs. Note that to ensure consistency between the different resolutions used (1 km NDVI, 0.05° CHIRPS RFE, and 0.25° ECMWF RFE), the coarser resolution data is resampled to the 1 km grid using nearest neighbour resampling.

5.2.2 Time domain

5.2.2.1 Dynamic masks and active season

The crop and rangeland AFIs are used to aggregate the values of a given indicator at the administrative unit level. For instance, if we are interested in retrieving the mean crop NDVI value for a given ASAP unit, we may compute the weighted mean of NDVI over the pixels belonging to the crop mask. The weighting factor will be the AFI of each single pixel involved in the calculation. However, in this way we would consider all the crop pixels, regardless the time of analysis t . This implies that we may consider the NDVI value of pixels that are located in an area used for crop production also in the periods of the year were the crop is not growing at all. To avoid such simplification we use the phenology information described in section 5.1.1. Although we use static crop 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 period. An example on synthetic data of the evolution of pseudo dynamic masks is provided in Figure 4.

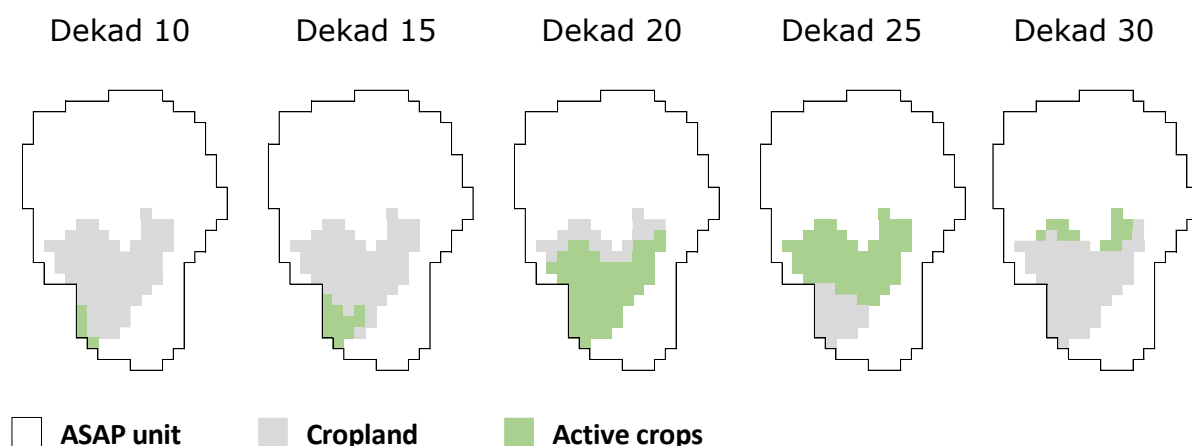


Figure 4. Graphical representation of dynamic crop masks. The panels show the static crop mask in grey and the temporal evolution of the pixels being labelled as active crop by the dynamic masks at selected dekads.

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

For the whole period characterized by active pixels covering a fraction of more than 15% of the cropland area, the unit is considered active. This rule excludes that anomalies occurring outside the main growing season are considered to be relevant.

It is noted that the active period of an administrative unit may be perceived to be longer than “expected”, as the analysts reported.

The origin of this effect is explained in Figure 5 (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 result, 15% of the areas is active for a periods of 20 dekads.

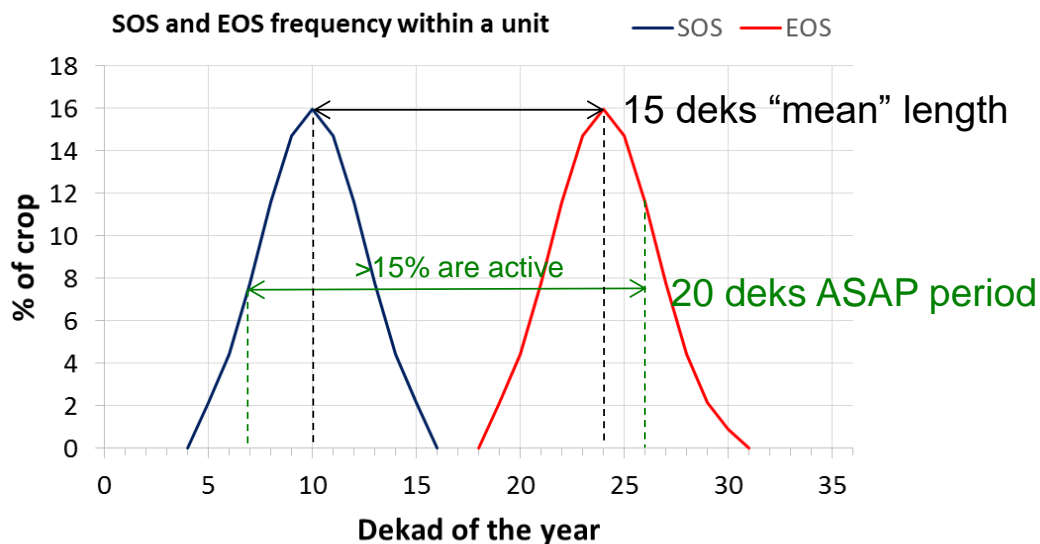


Figure 5. Frequency histogram of SOS and EOS for a hypothetical unit shown to explain the active period.

Finally, the presence of double growing season within the solar year (discussed in Section 5.2.2.2) may further increase the active period.

5.2.2.2 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 modality can be expected, it cannot be excluded that, particularly for large ASAP units, both modality 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. This timing will be thus related to most represented (in terms of area of active pixels) of the two. This “merging” of the two seasons was conceived in order to avoid treating mono- and bi-modal separately, with the consequence of having 4 targets by administrative unit, crop/rangeland, mono-/bi-modal.

The phenological stage has an effect on the warning level. In fact, during senescence, rainfall based indicators do not trigger a warning and only NDVI is used, as rainfall has little importance on crops during this phenological stage (although too much rainfall could cause high moisture in harvested grains).

In addition, a cumulative NDVI trigger during senescence is not a warning anymore, it is an ascertainment of a season failure.

5.2.3 Determination of critical area fraction by indicator

The warning level is based on the fraction of the area (of pixels having an ongoing growing season) being subjected to the different critical anomalies (zWSI, SPI3, and zNDVIc).

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 in one or more indicators and 2) the area concerned by the anomaly is relevant.

It is noted that, by taking 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 area with an active growing season at time of analysis:

$$CAF_x = \text{critical_area}_x / \text{active_area} \quad (4)$$

The subscript x refers to the indicator considered ($x = \text{zWSI}, \text{SPI3}, \text{zNDVIc}$). Note that all calculation are made taking AFI into account.

5.2.4 Determination of favourable area fraction for zNDVIc

As a positive anomaly in zNDVIc is univocally interpretable as favourable growth, we keep track of this possible event. In a similar way to CAF computation described in the previous section, we also compute a favourable area fraction for zNDVIc only, i.e. area subjected to large zNDVIc positive anomaly (as defined in Section 5.1.2.4) divided by the total active area.

5.2.5 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 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 4.1.1. Table 4 summarizes all the thresholds used in the warning classification system.

Table 4 List of variables and thresholds used by the warning classification system.

Name	Units	Meaning	Function	Value
<i>Pixel-level settings. Parameters used in the computation of the pixel-based phenology</i>				
<i>SOS_fract</i>	[-]	The season starts when the NDVI profile crosses this fraction of the amplitude in the growing phase	Determine SOS. The current set of phenology related threshold values was empirically determined with a trial and error process.	0.25
<i>EOS_fract</i>	[-]	Season ends at this fraction in the decay phase		0.35
<i>SEN_fract</i>	[-]	The senescence period starts at this fraction in the decay phase		0.75
<i>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 deviations.</i>				
<i>CT_zNDVIc</i>	SD	Detection of anomalous negative condition	Below this threshold the pixel is flagged as "critical" for zNDVIc (standardised cumulative NDVI over the season)	< 1

<i>CT_mNDVId</i>	%	Detection of anomalous negative condition	Below this threshold of the ratio $mNDVId / HISTORICAL\ MEAN(mNDVI) * 100$, the pixel flagged as "critical" for mNDVId	<-10%
<i>FT_zNDVIc</i>	SD	Detection of anomalous positive condition	Above this threshold the pixel flagged as "favourable" for zNDVIs	> 1
<i>FT_mNDVId</i>	%	Detection of anomalous positive condition	Above this threshold of the ratio $mNDVId / HISTORICAL\ MEAN(mNDVI) * 100$, the pixel flagged as "favourable" for mNDVId	> 10%
<i>CT_SPI</i>	SD	Detection of anomalous negative precipitation	Below this threshold the pixel flagged as "critical" for SPI (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 Critical Area Fractions.

<i>RUN_ACT_PC</i>	%	Percent of active pixels with respect to total (crop or rangeland mask \cap active area from average phenology)	Above this fraction of active pixels, the warning classification is performed.	> 15%
<i>CAFT1, CAFT2, CAFT3</i>	%	Percent of active pixels labelled as "critical" over the total active pixels for indicators zNDVIc, zWSI, and SPI3	Trigger a warning level 1 to 4	25
<i>MTATG0</i>	km ²	Minimum total agricultural [rangeland] area at GAULO level	The unit is not analysed for crops [rangeland] if the total agricultural [rangeland] area at the GAUL 0 level is below this threshold	1000
<i>MTAT</i>	km ²	Minimum total agricultural [rangeland] area	The unit is not analysed for crops [rangeland] if the total agricultural [rangeland] area is below this threshold	100
<i>MTAT2</i>	km ²	Maximum total agricultural [rangeland] area for which MTAT% is applied	The unit is analysed for crops [rangeland] if the total agricultural [rangeland] area is above this threshold, no matter MTAT%	
<i>MTAT%</i>	%	Minimum agricultural [rangeland] area fraction (agricultural [rangeland] area/total area * 100)	The unit is not analysed for crops [rangeland] if the agricultural [rangeland] fraction is below this threshold	1
<i>CED</i>	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

The level of the final warning depends on which indicators have a CAF exceeding the threshold and the modal phenological stage of the crop. To establish the final warning level, in our classification scheme we put emphasis on the relative importance of the various indicators and their agreement. We acknowledge that rainfall is the main driver of crop and rangeland growth and that NDVI is the result of such a driver (plus other perils

other than drought), so we rank the RFE and NDVI anomaly events with increasing warning level (Table 5).

Table 5. 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 zNDVIc is counted ONLY if also mNDVIId is critical.

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

Levels from 1 to 1+ are issued by meteo-based indicators (zWSI and SPI3). The lowest level in this group (level 1) is triggered a single meteo-based indicator (zWSI or SPI3) while the intermediate level (1+) is triggered by a prolonged deficit (during the last three months, SPI3). The higher level (1+) is assigned to the co-occurrence of the two conditions: a relatively long lasting deficit (SPI3) that is confirmed by the soil water balance model (zWSI).

An increased warning level (2) is assigned to the NDVI indicator as it shows that the growth of the vegetation has been affected, regardless of the causes.

It is recalled here that, as mentioned in Section 5.1.2.4, a critical zNDVIc is counted at the pixel level only if also mNDVIId is critical.

The level 3 (3 and 3+) is assigned to the co-occurrence of NDVI- 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 NDVI leads to level 3+.

The occurrence of a positive anomaly in zNDVIc 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.

Finally, the table shows that, during senescence, rainfall-based indicators do not trigger a warning and only NDVI is used because as rainfall deficit has little importance on crops during this phenological stage.

Concerning warning levels, additional valuable information may be extracted from the analysis of the evolution of the warning level in the preceding dekads. For instance, a persistency of warning of group 1 for some dekads may be regarded as more reliable than a first appearance of that warning level for the current dekad. Another example: a warning level 4 preceded by various warning levels in the previous dekads. In order to facilitate such analysis, when a warning is triggered, a matrix showing the temporal evolution past warnings is produced (an example is given in Figure 6).

6 Examples

An example of the result of the warning classification system is presented in Figure 7 for the time of analysis referring to 11/03/2019. ASAP units showing high levels of warnings are visible in southern Africa, affected below average precipitation in the first part of the season.

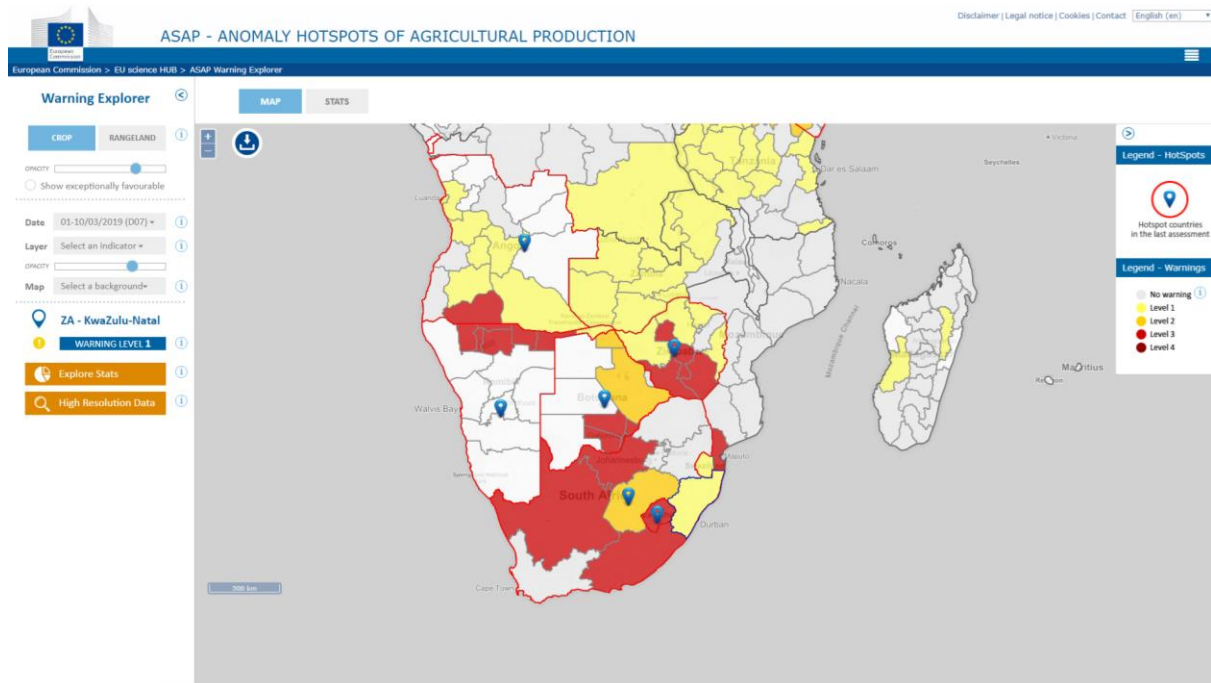


Figure 7. Example of warning classification referring to the time of analysis 11/03/2019, zoom over southern Africa.

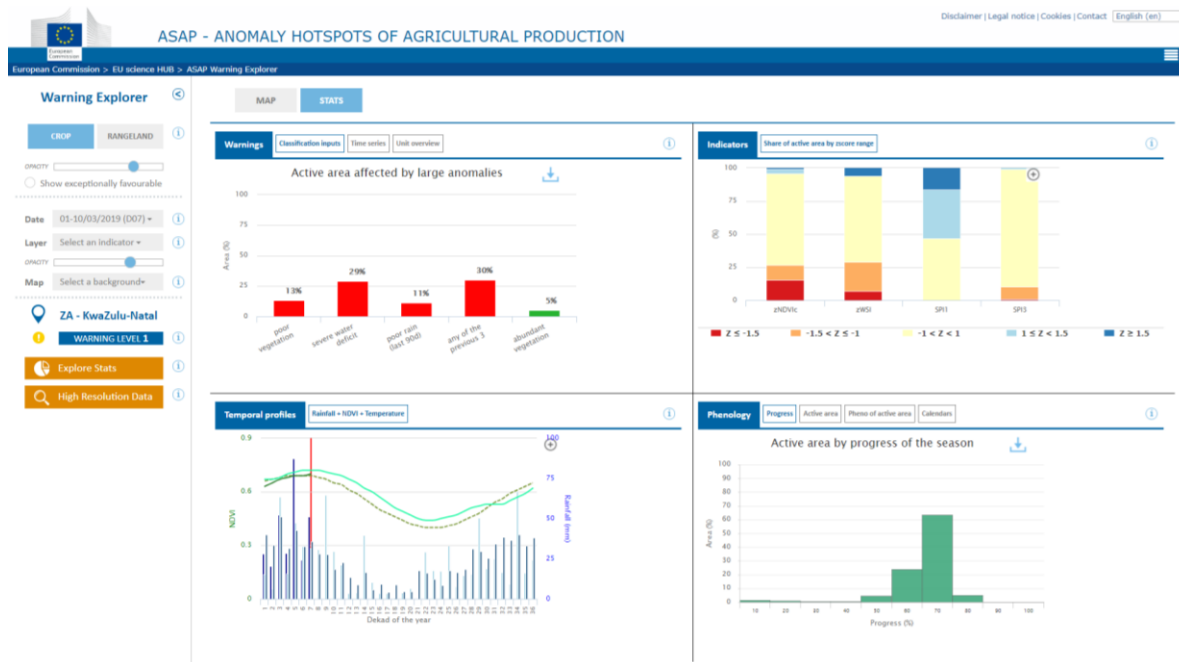


Figure 8 shows an example of level 1 warning in South Africa (ASAP unit KwaZulu - Natal). At the time of analysis 100% of the crop area was active (click "Unit overview" tab of the top-left panel "Warning"), 51% of the active crops were in the phenological stage of

“maturation” (same tab) with a median progress of the season of 70%. The critical area concerned by zWSI (“severe water deficit”) is above the 25% threshold and originates the level 1.

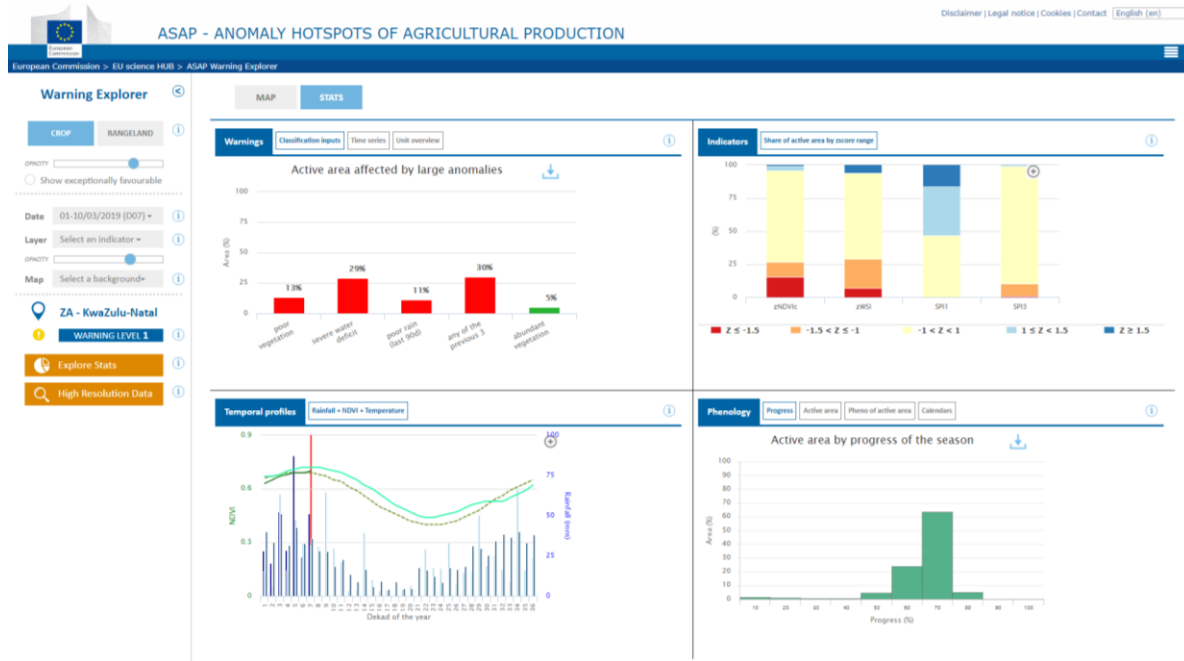


Figure 8. Example of a warning level 1 for crops. The top-left panel shows in red the critical area fraction for zNDVIc (“poor vegetation”), zWSI (“severe water deficit”), SPI3 (“poor rain (last 30d)”), the spatial union of the previous three (“any of the previous 3”), and in green the favourable area 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 NDVI 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.

7 Conclusions

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

The classification system is currently fully operational and publicly available at <https://mars.jrc.ec.europa.eu/asap/>. The "Warning Explorer" web GIS (<https://mars.jrc.ec.europa.eu/asap/wexplorer/>) with the warning classification for each ASAP unit at the global level is updated every 10 days. The hotspot map and overview based on analyst assessment is updated monthly between the 20th and the end of each month.

8 Way forward

Various modifications are currently being implemented to the automatic warning classification system, including: *i)* further refinements of the current cropland and rangeland masks; and, *ii)* use of air temperature data to detect heat waves.

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List of acronyms

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

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