From extreme weather to impacts: The role of the areas of concern maps in the JRC MARS bulletin

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ABSTRACT

Each month the JRC issues the MARS Bulletin detailing the agro-meteorological and expert analysis underpinning the assessment of European crops' status and yield forecasts. In this context a resume is provided to give an overview on the geographical distribution of eventual crop damages. The MARS Bulletin provides such information in a set of synthetic maps (Areas of Concern), produced in each Bulletin, depicting extreme weather events and their impact on crops that have occurred in Europe during the analysis period. The present article describes the mix of quantitative and qualitative datasets and methodologies that drive the delineation of the Areas of Concern (AOC) maps and evaluates their capability to resemble crop production losses. The quantitative analysis is based on the Mars Crop Yield Forecasting System (MCYFS) indicators coming from meteorological models, crop growth models and remote sensing data. Indicators are considered in absolute and relative terms and in their relation with standard statistical metrics. The outcome of the quantitative analysis is a set of potential Areas of Concern. Experts' judgment is thus necessary to discriminate potential results through a qualitative analysis focused on: past occurred events and climatologic conditions; agro-management practices; regional agricultural systems peculiarity and their historical resilience and resistance to adverse conditions. In this article the experts' judgment of the team of current MARS analysts, as used in the AOC analysis, is translated into a warning index. Such index condenses the specific contribution to the final production of each development stage and the adverse agrometeorological events occurred, as depicted into the AOC maps. The warning index is computed at country scale for the past five agricultural seasons, from season 2011-2012 to season 2015-2016. Two crops are considered, winter wheat and grain maize as proxy for winter and summer crop groups. The warning indexes calculated are then compared to the national production in a qualitative way. To support the analysis few study cases are presented. The findings of this article highlight that the events depicted in the AOC maps are informative about production losses and specific knowledge is needed to full understand the information carried.

1. Introduction

The JRC MARS Bulletin 'Crop monitoring in Europe' is a regular publication from the JRC providing short-term crop yield forecasts and crop condition analysis for the EU-28 Member States and neighboring countries. This information is complemented with the Area of Concern (AOC) maps. This set of maps plays a significant role in synthesizing weather and crop conditions at European scale, in delineating regional and transboundary events and in translating weather events into crop impacts. The objectives of the AOC maps are twofold: a) to map at a European scale regional weather events and their potential crop impacts summarizing in one map the individual agro-meteorological country assessments of the bulletin and b) to issue a warning for the mapped regions, with respect to possible yield and production losses. This regional warning does not necessarily lead to production losses at national level due to compensatory effects but it might do so. However the information in the AOC map is not crop specific, since it addresses crop groups (e.g. winter crops, spring crops, summer crops).

The AOC maps, as delineated in this paper, are present in the bulletins since the agricultural season 2011–2012 and are widely used by

MARS Bulletin stakeholders. They are usually displayed in the short-term outlook issued by the Directorate General for Agriculture and Rural Development (European Commission – DG AGRI, 2016) and in the dashboard for cereals (European Commission – DG AGRI, 2017aa), and oilseed crops (European Commission – DG AGRI, 2017bb).

The implementation of the crop monitoring system by JRC is regularly defined on a clear legal basis agreed with the EU Member States. Currently it operates under the European Regulation 1306/2013 (European Parliament, 2013).

The information for the JRC MARS Bulletin stems from the MARS Crop Yield Forecasting System (MCYFS). The MCYFS is based on near real time acquisition and processing of three main data sources: weather data (observations and forecasts), crop model simulations, and biophysical parameters derived from satellite remote sensing. Based on this information, the team of MARS analysts produces the national crop yield forecasts for the most common annual crops, and it provides agro-meteorological assessment of crop growth conditions at country level.

The paper discusses the role that the AOC analysis has in providing synthetic information, in near real time, about weather-related crop production losses, beyond damage to crop yield only. Furthermore, it

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discusses if the AOC analysis can support an enhanced consistency between the issued warnings, qualitative country specific assessments and national crop production.

2. Materials and methods

2.1. Areas of Concern – AOC

The crop monitoring information provided in the JRC MARS Bulletin analyses up to 15 crops in 35 countries. To synthesize the information each bulletin offers a set of maps that depict the main meteorological events and their possible damages to crops. This set of maps is named *Areas Of Concern (AOC) maps*. They are the result of a dedicated analysis, based on a decision process driven by expert knowledge on pre-defined guidelines, examining the information provided by the MCYFS (see 2.2). Each AOC analysis results in the determination (geographically and thematically) of the adverse meteorological events, the *AOC extreme weather event map*, and their negative effects on crop, the *AOC crop maps*. Each delineated impact in the AOC crop maps shall have its geographical counterpart in one of the elements in the AOC weather map. Indeed meteorological events could occur without necessarily causing damage to crops, while a crop damage is always conditioned by a meteorological driver, displayed in the AOC weather map. The AOC crop maps are divided according to crop groups: winter crops (winter wheat, winter barley, rye, triticale, and winter rapeseed), spring crops (spring barley, spring wheat, sugar beet and potato) and summer crops (sunflower, grain maize). Fig. 1 provides an AOC set of maps as example.

2.2. Quantitative data

The MCYFS provides the essential datasets used in the AOC analysis: interpolated observed weather data from a network of meteorological stations across Europe; and medium range weather forecasts from the European Centre for Medium Range Weather Forecasts (ECMWF) for the AOC map on extreme weather events. Crop growth indicators from WOFOST crop model simulations and remote sensing datasets (typically METOP-AVHRR) are used for the crop impact maps. For detailed references to each one of these products and their use in the MCYFS please refer to the WikiMCYFS (European Commission, 2017). National and regional statistics on crop yield, area and production are obtained from Eurostat (European Commission – DG AGRI, 2017a).

From each dataset, a subsample of variables is considered. Table 1 presents the list of used variables used and the associated indicators.

Table 1
Variables and their indicators used in the AOC analysis process.

Variable	Indicators
Precipitation	Daily values (A) and cumulated (A, AA, RA)
Temperature (maximum, average and minimum)	Daily values (A), average and accumulated (A, AA)
Radiation	Cumulated (RA)
Climatic water balance	Cumulated (AA, RA)
Crop specific indicators (Water limited and potential above ground biomass, storage organs yields, relative soil moisture, development stage, frost kill damage)	Dekadal (A, AA, RA) and cumulated (A, AA, RA)
fAPAR (remote sensing retrieved)	Dekadal (A, RA) and cumulated (AA, RA)

A – Absolute values, AA – Absolute anomalies against the Long Term Average (LTA), RA – Relative anomalies against the LTA. References for each source are available at the WikiMCYFS.

2.3. Qualitative information

In social sciences tacit knowledge is a concept that describes the knowledge that can't be fully codified, but that has a relevant role in problem solving applications (Eraut, 2000; Leonard and Sensiper, 1998). In the AOC analysis tacit knowledge plays a major role in six areas: (1) genetic varieties used, their phenological calendar, and their stress-resistance against weather driven impacts. MCYFS is calibrated at continental scale with a relatively limited number of varieties for each crop (Ceglar et al., 2018) and significant differences could emerge between reality and MCYFS outputs; the understanding of these differences mostly belongs to the tacit knowledge domain. (2) Timing as well as the modality of pest and disease control and fertilization practices. (3) Irrigation practices and water availability. Indeed the main land cover maps provide information about permanent irrigation (Arino et al., 2007; Büttner and Kosztra, 2011) but none is usually available for non-permanent irrigation. (4) Mitigation capacity of the agricultural systems due to economical, infrastructural, and advanced know-how capability (Robert, 2002). (5) Historical resilience and resistance to certain weather conditions, based on the observation of similar events in the past. (6) Information from press, social networks and other public sources in the frame of collective intelligence in Web 2.0 (Bonabeau, 2009), provided that they are regularly cross-checked with other reliable sources.
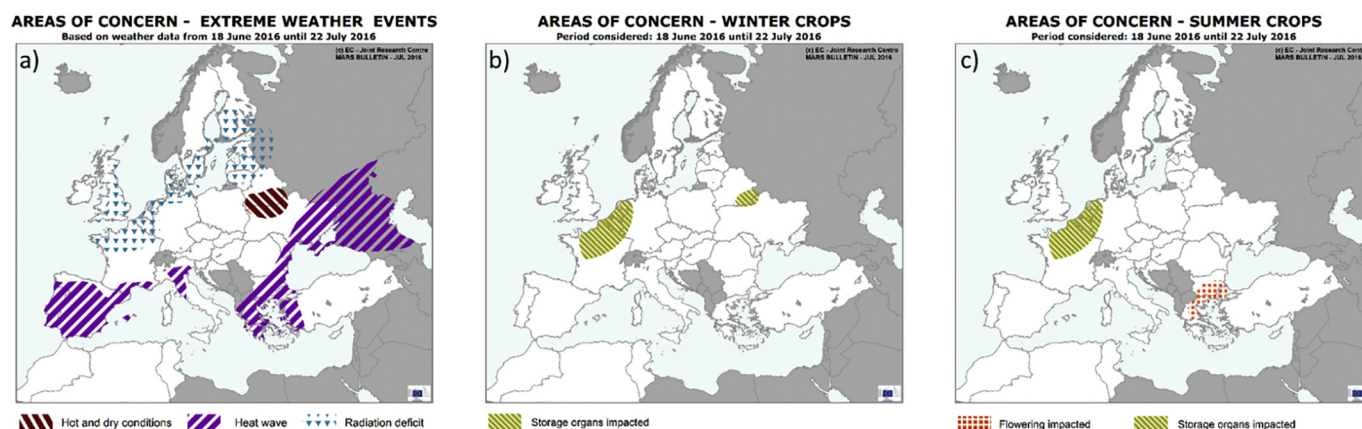

Fig. 1. AOC maps from the July 2016 MARS bulletin issue. Map a) synthetizes the meteorological adverse weather events occurred during the period of analysis – cited in the subtitle – while b) and c) show impacted regions with crop damages for winter crops (b) and summer crops (c).

Table 2

In the left column, the meteorological classes as defined in the AOC maps of 2016, in brackets the different naming conventions that were used since 2012. In the right column, the list of the criteria and their associated thresholds that trigger a meteorological event to be mapped. Even if an event is triggered, is the expert analysis who decides if this should be included in the AOC meteorological map.

Meteorological event	Criteria
Rain excess or rain deficit (over-wet, rain surplus, torrential rain, hailstorms and heavy rains, dry conditions, critically dry, exceptional rain deficit)	Cumulated rainfall RA: ± 25% observed in two or more analysis period RA: ± 50% over the analysis period One or more days with daily precipitation > 50 mm
Radiation deficit	Cumulated radiation RA: ± 25% observed in two or more analysis RA: ± 50% over the analysis period
Heat wave (hot spell, hot days, exceptional number of hot days)	Three or more days with Tmax > 30 °C and no precipitation.
Cold spell (frost impact)	One day with Tmin < −18 °C, two or more days with Tmin < −10, three or more days with Tmin < 0 °C and average Tmin has RA < −50%
Hot and dry conditions	Three or more days with 25 °C < Tmax < 30 °C, no precipitation, average Tmax has RA > 0%
Drought	*Rain deficit* event observed for at least two or more analysis and evidence of effect on crops from remote sensing observation
Temperature accumulation surplus or *temperature accumulation deficit (Deficit of Tsum, Surplus of temperature accumulation, Deficit of temperature accumulation, exceptional deficit of Tsum)*	Sum of average temperatures (Tsum) RA: ± 50% over the analysis period

2.4. Geographic and temporal resolution

2.4.1. Geographic coverage and resolution

The AOC analysis covers the countries included by the JRC MARS Bulletin: EU-28 Member States, Belarus, Ukraine, Russia (south western oblasts only), Turkey and Maghreb countries (Morocco, Algeria and Tunisia). The MCYFS provides all the information at the required regional detail needed for the AOC analysis. The spatial data framework consists in a 25 km grid. As a consequence, meteorological quantitative data have a 25 km resolution (European Commission, 2017), which corresponds to the lower boundary of the meso-beta scale (20–200 km) in meteorology. Such resolution is appropriate to catch most extended weather events as they occur between meso-beta and meso-alpha scale (200–2000 km) (Orlanski, 1975). Remote sensing and crop simulations are aggregated at administrative level (Genovese et al., 2001). The crop distribution information is based on regional statistics with a resolution limited to the regional (NUTS2 or NUTS3 (European Commission, 2015)) or macro-regional scale (NUTS1), when available. The qualitative information has different geographical resolutions and varies from punctual (e.g. single report from a farmer on social media) to regional (e.g. news from the mainstream media). Usually, such information is condensed by the AOC analyst to a generic regional (NUT3 to NUTS2) or above-regional knowledge (NUTS1). Therefore the AOC analysis has a resolution of a generic administrative unit, in size dimensioned between NUTS3 and NUTS2, and detailed enough to be informative but coarse enough to be synthetic.

2.4.2. Temporal resolution

Each AOC analysis period covers around 60 days using interpolated observed weather and weather forecast data. Each consecutive analysis overlaps from 20 up to 29 days. To avoid redundancy, each event shall be presented only once in the AOC maps, unless the event characteristic changes. Each event could be classified as a short-term event (lasting one or few days), a medium-term event (from 20 to 60 days) and a seasonal event (from 60 to 90 days or more); the event classification is not mentioned in the map legend. To catch an event, a proper time-window is considered, with an amplitude equal or slightly longer than the event's time resolution.

2.4.3. AOC definition and mapping

The AOC analysis monitors the potential hazards of an agricultural season that could threaten: a) crop yield, b) crop harvested area, or c) grain quality.

a) Crop yield is the result of the interaction between genetic, environment and management (Hatfield and Walthall, 2015; Spiertz, 2012). AOC analysis considers crops as genetically adapted to the environment, and thus deals only with weather events that, influencing crop growth and the management, potentially reduce the expected yields (Evans and Fischer, 1999).

b) In terms of crop harvested area, the inter-annual variability is mostly due to socio-economic reasons (van Vliet et al., 2015) or relates to medium to long term trends, like climate change (Olesen et al., 2011). The AOC analysis focuses only on those short-term meteorological events that could reduce the harvested area like frost kill or severe drought.

c) The JRC MARS Bulletin does not have a specific focus on grain quality monitoring; nevertheless, weather conditions that could cause a significant quality reduction (Smith and Gooding, 1999; Toscano et al., 2014) are considered and mapped in the AOC analysis.

2.4.4. Meteorological events definition

The main weather conditions that influence crop growth are: rain, temperature, and radiation (Hall, 2000; Porter and Semenov, 2005). As crops are expected to be adapted to the climate where they are grown, the main hazards are associated with unseasonal weather. Weather events could directly damage crops if certain conditions are met (Barlow et al., 2015; Ceglar et al., 2017; Hlavinka et al., 2009; Trnka et al., 2014) or just determine suboptimal growing conditions that reduce the crop performances in a nonlinear way, like the relation between photosynthetic activity and temperature (Porter and Semenov, 2005). Furthermore, crops along the agricultural season could be exposed to an ensemble of negative, or just suboptimal, meteorological events whose impacts are complex to be assessed. As a consequence, the AOC meteorological analysis is based on a set of different thresholds that leaves the analyst a certain degree of freedom to come to a conclusion about the hazardousness of an event. The quantitative elements that guide the AOC analysis are reflected in the legend of the AOC meteorological maps. Table 2 lists the AOC meteorological events that can be mapped in the AOC map and the criteria that trigger them. The regions where the conditions are as in Table 2 occur are evaluated by the experts' analysis and, if confirmed as a concern, are mapped in the AOC weather map.

2.4.5. Crop events definition

The relevance of the weather events is defined in association with the crop development: a severe event might not represent a risk per se

but could result critical depending on the crop phenological development at the time of the event. The timing of crop phenology has a certain degree of uncertainty in the MCYFS (Ceglar et al., 2017): crop model implementations in MCYFS use fixed sowing dates. The remote sensing platforms used in the MCYFS cannot provide crop specific information due to the miss-match between pixel size (mostly 1 km resolution) and the average European field size (Duveiller and Defourny, 2010). The crop phenological assessment thus relies on expert evaluation, if necessary with the support of external tools and information (FranceAgriMer, 2017), and could result coarse (van Bussel et al., 2011) but sufficient for the AOC resolution as in 2.4.1.

The AOC analysis distinguishes five main phases that compose a generic agricultural season, hereafter named agricultural season block (ASB), and are used as legend classes in the AOC crop maps. Each ASB is associated with specific codes of the extended BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische industrie) phenological scale (Hess et al., 1997). A description of the main reasoning that drives the analyst's decision in linking the meteorological event to a crop event is proposed below for the five ASB for winter wheat.

ASB 1. : sowing or emergence (from sowing to BBCH growth stage 0).

The reference sowing calendar and sowing window are derived from the MCYFS, but sowing dynamics are complex and weather dependent (Cooper et al., 1997; Iizumi and Ramankutty, 2015; Peltonen-Sainio and Jauhiainen, 2014). The AOC analysis considers rainfall and minimum temperatures (Ewert, 1996) as possible hazards: rain deficit or excess could shift sowing activities out of the optimal sowing window and consequently expose crops to suboptimal temperatures during germination and emergence. Such meteorological hazards often do not harm crops directly but delay the phenological cycle and expose plants to a higher risk of frost kill in winter – crops don't have the time to develop frost resistance before the coldest months – or to higher probability of heat stress – since the delay in crop development could lead flowering or grain filling to take place toward summer, when the probability to be affected by heat waves is much higher (Porter and Semenov, 2005). In some regions, expertise suggests that farmers prefer to sow alternative crops instead of exposing crops to possible damages. Weather events could also cause direct damages to seed germination, like severe frosts or heavy rainfall.

ASB 2a. : vegetative growth – winter period (from BBCH growth stage 1).

Winter wheat productivity is linked, among other factors, to the effectiveness of the vernalization processes (Porter and Gawith, 1999). During the AOC analysis, unusually cold temperatures, with minimum temperatures at least below $-8\,°C$, triggers the meteorological event *cold spell*. Possible frost kill events are evaluated according to the crops hardening conditions (Lazăr et al., 2005) and snow layer thickness (Bergjord et al., 2008). In the AOC analysis, unusual mild temperatures are reported, as well as full hardening could be inhibited and chlorosis could occur at not-so-cold temperatures.

ASB 2b. : vegetative growth (from BBCH growth stage 1 to BBCH growth stage 4).

During vegetative growth, three groups of hazard are considered: 1) Excess of precipitation: it could physically damage crop stems and cause lodging (Acreche and Slafer, 2011; Fischer and Stapper, 1987). In other cases it could cause root anoxia or nutrients uptake limitations due to waterlogging (Herzog et al., 2016; Trought and Drew, 1980), or favor pest and disease spread (Nakajima et al., 2008) and hamper agro-management activities for their mitigation. 2) Reduced precipitation: it could reduce vegetative growth rates (Porter and Gawith, 1999). The extension of a dry period could trigger a drought event on the map: AOC analysis expects that an agricultural drought is present only in the case of evidence of reduced plant growth or early senescence, obtained from observed data or external sources. 3) Temperature anomalies: could determine suboptimal physiological processes (Porter and

Semenov, 2005). Temperature anomalies could even shift critical phenological stages exposing crops to an increased risk of damage, as in the Mediterranean regions, where late flowering results in crops being more exposed to heat stress (Fontana et al., 2015).

ASB 3. : flowering (from BBCH growth stage 5 to BBCH growth stage 6).

Damage occurring during flowering is difficult to recover for the crops due to the short length of the phenological stage and because of the plant physiology itself. Several studies have highlighted the relation between damage to flowers and yield reduction (Barlow et al., 2015). Flowering is sensitive to low and high temperatures that could reduce flower fertility (Challinor et al., 2005; Thakur et al., 2010). Intense rainy events could physically damage the flowers, while constant rains could reduce pollination. At the same time, the elements that threaten crop during the previous stages are still a menace and are taken into consideration.

ASB 4. : grain filling (from BBCH growth stage 7 to BBCH growth stage 8).

During grain filling, two processes are considered: the time for grain formation and the capability of the plant to translocate biomass to the grains (Farooq et al., 2011). The first is mostly linked with minimum and maximum temperature that could kill grains or reduce their weight by shortening the grain filling period (Barlow et al., 2015). This latter process could occur even under water stress conditions. The second process is linked to processes driven by low radiation or soil moisture excess: such conditions hamper biomass translocation from the green tissues to the grains and final yields are reduced. (Nuttall et al., 2017; Yang and Zhang, 2006).

ASB 5. : harvest (from BBCH growth stage 9 to harvest).

The main limitation factor for harvest operations is the excess of rains that could cause crop lodging, grain detachment, increase the pest and disease pressure, and have a negative effect on the grain quality (Smith and Gooding, 1999) with possible additional costs for drying the grains.

2.4.6. AOC final mapping

When the analyst's judgment identify that conditions described in 2.4.4 and 2.4.5 are present for a certain region, those are translated into mapped areas. In case a weather event is triggered and no crop event is associated, the region is reported in the AOC weather map even if its effect does not immediately threaten crops. If a weather event has a negative effect on crop stands, the region is reported on the AOC maps for weather and crop events.

3. Evaluation of the AOC

The AOC maps are here evaluated with respect to their forecast potential to indicate production losses. AOC maps from 2012 to 2016 are compared against winter wheat and grain maize production losses. This evaluation aims to understand the effectiveness of the AOC maps to describe the effect of unfavorable weather conditions along the agricultural season. The assessment is done at country level, under the assumption that if a region is reported in the AOC maps it has a relevance for the overall country production.

3.1. Crops and country selection

The AOC analysis considers the hazards of meteorological events differently according to each group of crops. To simplify the evaluation, the present paper focuses on cereals, due to their economical relevance in Europe. Among cereals, the two most important crops produced in Europe were selected: winter soft wheat, representing the winter crops group, and grain maize, representing the summer crops group.

Crop production is generally unevenly distributed among the European Union. In the last ten years, 75% of winter soft wheat
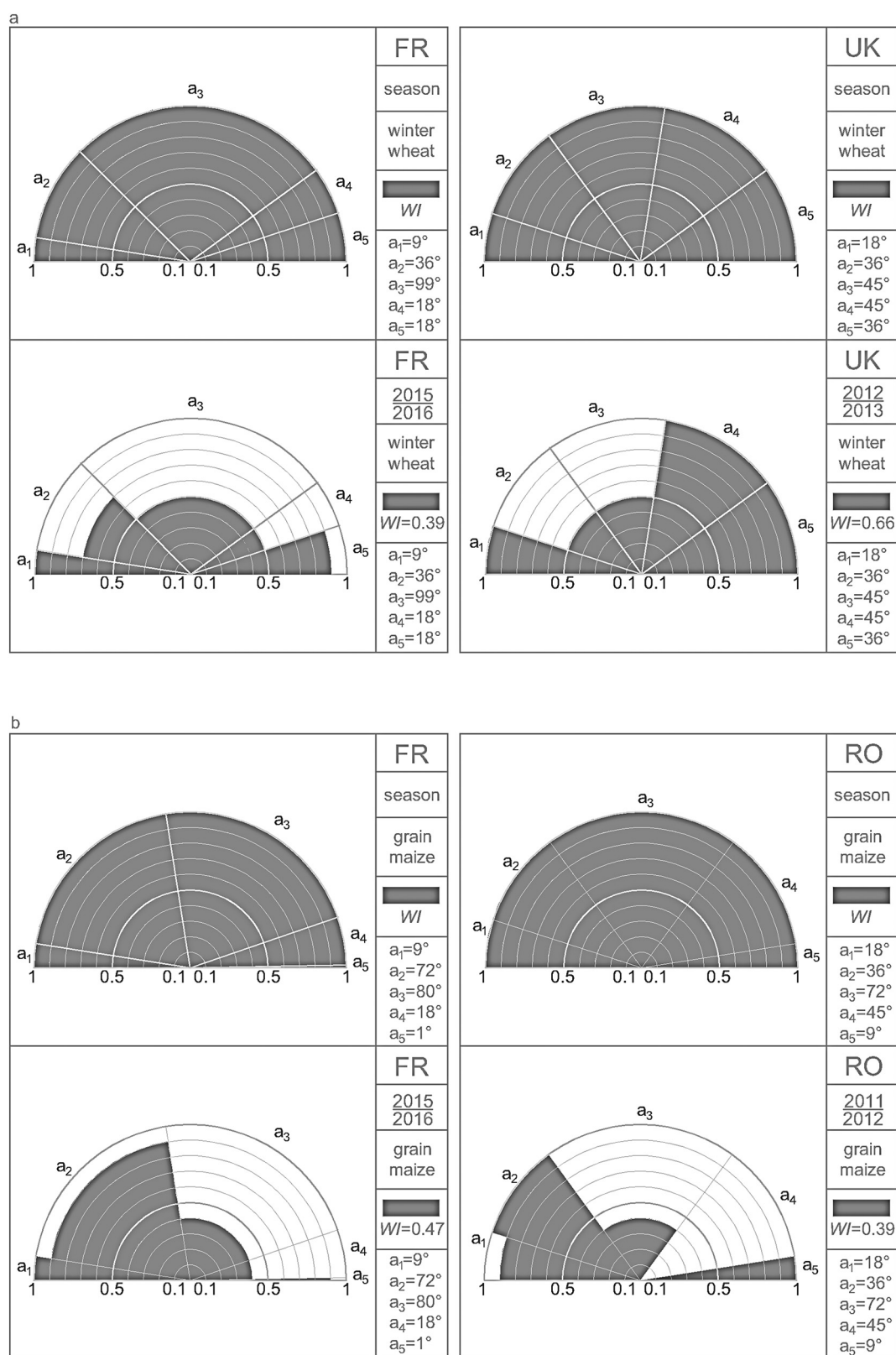
Fig. 2. The representation of the component of the agricultural season, divided according to the AOC ASB as seen by the MARS analysts. In the first row of the upper panel (a), two graphs representing the theoretical contribution of each ABS, expressed in degree, for the winter wheat assessment for France (FR) and the United Kingdom (UK). In the second row, the two graphs represent the season specific AOC assessment done for the UK (season 2012–2013, WI = 0.66) and FR (season 2015–2016, WI = 0.39). In the lower panel (b), the first row presents two graphs about the theoretical contribution of each ABS, expressed in degree, for the grain maize assessment for France (FR) and Romania (RO). In the second row, the two graphs represent examples of the season specific AOC assessment done for FR (season 2015–2016, WI = 0.47) and RO (season 2011–2012, WI = 0.39). In the Annex, the evaluation for the other country-year combinations is presented.

production (European Commission – Eurostat, 2017) is distributed among six main producers (France, Germany, the United Kingdom, Poland, Romania and Spain), while 90% of the production is covered by the previous six plus other five (Denmark, Bulgaria, Hungary, the Czech Republic, and Italy). The remaining 10% are distributed among the other 16 countries. For grain maize, the situation is similar with ten countries producing 90% of the EU-28 production: France, Romania, Italy, Hungary, Germany, Spain, Poland, Austria, Bulgaria, and Greece – thereof the first six cover 76% of the production. To be coherent with the AOC analysis, that reports only about relevant regions, the present evaluation considers only those countries that, based on last ten years average, cover 90% of the EU-28 production for winter soft wheat and grain maize, respectively.

3.2. AOC analysis versus production losses

To evaluate the AOC capability to monitor the agricultural production, as a consequence of weather conditions, and identify regions under sub-optimal conditions, a comparison against winter soft wheat and grain maize production is conducted at country level. First, AOC events have been detected and associated with the selected countries. All the AOC maps produced from the season 2011–2012 to the season 2015–2016 are considered. Each event, meteorological or crop, has been attributed to the respective country; events have been discharged if the mapping doesn't cover a meaningful part of the country's cropland, on the base of expert judgment. While the association between a crop event and a ASB is explicit, the association between an AOC meteorological event and an ASB relies on a crop calendar, expert-based (European Commission – DG JRC, 2017.): each AOC meteorological event is associated with the most relevant ABS occurring during the AOC analysis period; the relevance of an ABS is given by the importance emerged from the expert group assessment.

In a second step a warning index (WI) has been computed for each country-year combination. National crop production is represented as the area of a semicircle with a radius of one, as shown in the panels of the first row of Fig. 2a and Fig. 2b. The semicircle is divided into five sectors representing the five ASB: the angle's amplitude of each sector expresses the a-priori expert knowledge. Such amplitudes were defined through a qualitative group assessment in which the MARS analysts were asked to quantify the weight of each ASB to the final production for each country, for winter wheat and maize separately. The radius length of each sector describes the evaluation of possible damages to the agricultural production. The area of each sector thus represents the contribution of each ASB to the final production and is computed as in Eq. 1.

$$A_s = \frac{\pi}{360°} R_s^2 a_s \qquad (1)$$
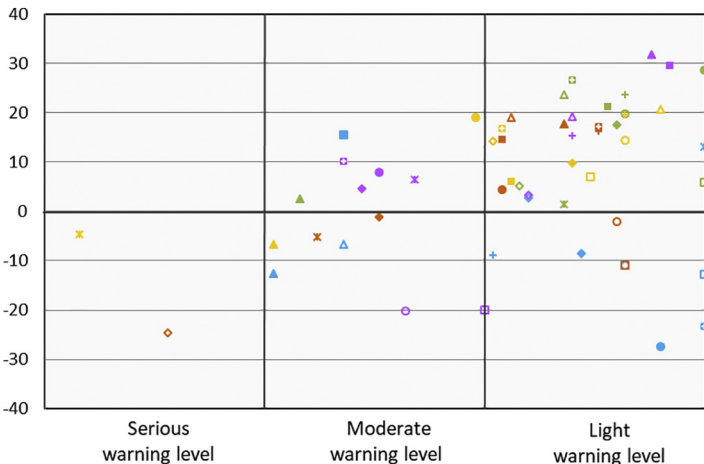
A_s is the sector's angle amplitude, country specific, defined by the MARS group of yield analysts, and reported for all the countries in the supplementary material. R_s is the radius length defined as in Eq. 2:

$$R_s = 1 - (M_s * W_m + C_s * W_c) \qquad (2)$$

With R_s the radius of the sector, M_s the number of meteorological events without any associated crop event during the considered ASB and C_s the number of crop events in the same ASB. W_m is the weight associated to the meteorological event and with a value of 0.1, and W_c is the weight of the crop impact event and with a value of 0.5. The two values represent the intensity of the damage on crop production and are assigned qualitatively, under the assumption that a meteorological event shall be less relevant than a crop event. By definition, a crop event includes the presence of a meteorological driver and thus, in the presence of a crop even, its driver is not included in the Eq. 2.

Eq. 3 presents the warning index WI expressed as the ratio between the sum of all sectors area A_s and the area of the theoretical season without any negative impact, represented by the whole semicircle's area A.

$$WI = \sum_{s=1}^{5} A_s/A \qquad (3)$$

WI assumes values from 0 to 1 and is further classified, as in Table 3, in a scale representing the warning level related to a negative production anomaly. Fig. 2 reports examples for the winter wheat and the grain maize assessment. Finally, the index has been transformed in the associated warning level as in Table 3, plotted against the national production anomalies computed against the average of the previous five years (Figs. 3 and 4).

4. Results

The AOC analysis produced 88 maps in the five season period between 2012 and 2016: 46 meteorological and 42 crop maps. The most represented element among the AOC meteorological event is rainfall with 35 occurrences for *excess of precipitation* and 34 for *deficit of precipitation*; the least represented are radiation anomalies with one event

Table 3
Qualitative classification of the WI as a scale of warning for possible production losses.

Values of WI	Warning level
1–0.75	Light warning level (LWL)
0.74–0.5	Moderate warning level (MWL)
< 0.5	Serious warning level (SWL)

Fig. 3. on the x axis, the values of the qualitative category that represent the warning level for possible winter wheat production losses; on the y axe, the yearly production anomalies computed against the relative five-year average. The colours represent the season and the symbols the different countries. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 4. on the x axis, the values of the qualitative category that represent the warning level for possible grain maize production losses; on the y axis, the yearly production anomalies computed against the relative five-year average. The colours represent the season and the symbols the different countries. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
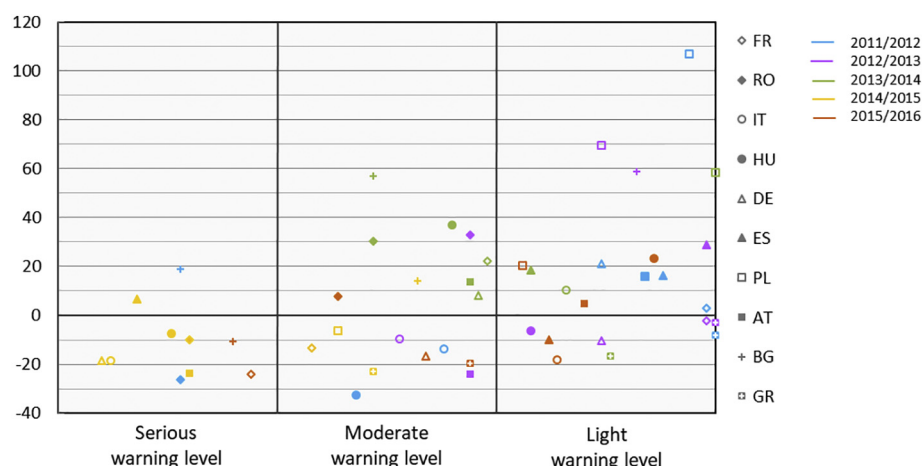
only. Since the 2011–2012 season, 28 crop events have been mapped for winter crops while only 17 for summer crops. Among them, 11 occurrences have been recorded about possible damages to winter crops storage organs and 8 for summer crops storage organs. Crop events related to unfavorable harvest condition are zero, as well as the sowing events related to summer crops.

4.1. Winter soft wheat assessment

Table 4 presents the anomalies of the statistics, computed against the previous five-year average, and the *WI* values computed for winter wheat, for each country-year combination.

Fig. 3, presents the winter soft wheat evaluation results. Theoretically,

positive anomalies in production are expected to have a LWL, while negative anomalies are expected to be in SWL. The intermediated MWL is expected to be equally balanced without a strong positive anomaly.

In Fig. 3 around 85% of the strongest positive anomalies (production anomaly > 10%) remain in the class of *LWL*, as expected. Just one case out of nine with production anomalies < − 10% is classified in the *SWL* class, while six are attributed to the *LWL* class and two to the *MWL* class. The cases in between – production anomalies included between ± 10% – are distributed among the *MWL* and *LWL* classes with just one case in the *SWL* class.

The majority of the cases falls in the class *LWL* – 40 out of 55 – with 31 cases that did not present production losses and could be considered properly assessed by AOC analysis. Among the nine cases with

Table 4
For each country (lines) – season (column) combination are reported, the anomalies of area (A%, top-left), yield (Y%, top-right) and production (P%, bottom-left) as well as the values of the WI (bottom-right), calculated for winter wheat. Anomalies are computed as the difference against the previous five-year average, expressed in percentage. In shade of red are highlighted the negative anomalies, in shade of green the positive anomalies, yellow colour represents around-the-average anomalies. Darker the shade of the colour, stronger the anomaly. No highlight is proposed for the WI values.

A(%)	Y(%)	2011/2012		2012/2013		2013/2014		2014/2015		2015/2016	
P(%)	WI										
BG		4.54	10.99	14.94	12.93	7.49	13.37	-7.59	15.58	-0.48	20.00
		15.41	0.59	29.41	0.96	21.07	0.89	5.98	0.78	14.53	0.77
CZ		-4.24	-19.95	1.31	8.82	0.87	25.79	-0.65	17.95	3.49	13.38
		-23.40	1	10.04	0.59	26.47	0.85	16.78	0.77	17.07	0.88
DE		-7.90	-0.70	-1.99	6.57	1.61	15.49	3.40	6.06	1.00	-2.21
		-8.65	0.86	4.49	0.61	17.36	0.90	9.69	0.85	-1.28	0.63
DK		-17.06	4.67	-21.08	0.85	-2.88	8.66	-4.89	11.30	-9.19	-2.09
		-12.93	1	-20.02	0.75	5.86	1	6.89	0.87	-11.10	0.91
ES		18.33	-21.09	12.49	16.07	11.49	-6.07	5.49	-13.04	-3.20	19.81
		-11.89	0.51	31.61	0.94	2.53	0.54	-6.86	0.51	17.59	0.84
FR		-0.34	3.01	1.13	1.85	2.11	3.01	4.25	9.33	2.71	-27.30
		2.70	0.8	3.18	0.8	5.06	0.79	14.08	0.76	-25.38	0.39
HU		-1.24	-8.37	1.74	13.38	5.22	17.28	-2.92	23.31	-2.98	19.73
		-9.04	0.76	15.17	0.85	23.51	0.91	19.46	0.91	16.08	0.88
IT		-1.10	14.35	7.81	-2.38	2.45	-0.66	-5.07	2.61	-8.75	3.66
		12.95	1.00	6.33	0.67	1.43	0.84	-4.72	0.29	-5.23	0.56
PL		-27.98	2.32	2.31	7.36	10.13	17.97	14.92	6.54	2.52	2.74
		-27.48	0.95	7.85	0.63	28.54	1.00	19.00	0.74	4.23	0.77
RO		-3.53	-3.35	1.51	16.88	2.30	20.31	2.40	17.71	3.63	14.89
		-6.74	0.59	19.07	0.85	23.53	0.84	20.64	0.95	18.86	0.78
UK		3.82	-14.11	-17.22	-3.89	4.20	14.83	-3.08	15.27	-2.45	0.59
		-11.09	0.91	-20.21	0.66	19.65	0.91	14.32	0.91	-2.14	0.90

production losses, six belong to 2012 AOC assessment. In 2012 the distinction between meteorological and crop events was not formalized and AOC maps were not able to provide clear evidences of production losses. Nevertheless, the 2012 AOC analysis highlighted for the United Kingdom and Ireland excess of water that caused yield losses (−14.1% as in Table 4; the symbol in Fig. 3 overlaps with the symbol DK-2015/2016) (The United Kingdom – Department for Environment Food and Rural Affairs, 2013). For the United Kingdom, the −2.1% of production loss was considered unlikely even during the season 2015–2016 (The United Kingdom – Department for Environment Food and Rural Affairs, 2016). Such a minor anomaly is mostly due to wet conditions at the beginning of the summer, which locally increased weed, pest and disease pressure. Meteorological data recorded such wet conditions, but the AOC analyst considered the *Rain-excess* condition not critical and left the United Kingdom free from impacts during the most sensitive stages of flowering and grain filling, highlighting only sub-optimal meteorological conditions during spring. To notice is that twice, in 2012 and 2016, the AOC analysis for Denmark was not able to link a SWL to the production losses. In Denmark, from 2012, the winter soft wheat area decreased from 720,000 ha for the period 2007–2011 to an average of 590,000 ha for the period 2012–2016. Such a strong trend suggests that production anomalies that relate to area changes are not induced by weather conditions (and the LWL issued). In 2012, the AOC analysis assigned LWL to the Czech Republic, even if winter wheat production anomaly resulted around −23%. Such anomaly was indeed weather-depend and caused by lasting drought conditions during spring and summer (Intersucho, 2017; Potopová et al., 2015). In this case the analyst underestimated the effect and the extension of such conditions minimizing them (European Commission – DG JRC, 2012). Similar reasoning is valid for the same year in Hungary where in 2012 a low waring level corresponds to a production anomaly of −9%. In this case AOC highlighted few meteorological impacts but underestimated their impact on crops (see discussion above on 2011–2012 season).

In the *MWL* class 13 points are present, almost equally divided between positive and negative anomalies. Five cases belong to the 2012–2013 assessment, when the distinction between meteorological and crop events was introduced. Among those, the case of Denmark is already presented while, for the United Kingdom, the low production is driven by a reduced planted area, probably due to the consequences of 2012 extensive floods as reported by specialized press (Farmers Weekly, 2017). Spain is presented with three points among which only 2013–2014 present positive production anomalies. In 2014, the AOC analysis reported few crop events but affecting the most sensitive stages among which the damage to winter crops storage organs during late spring in central Spain. If the winter wheat statistics for 2014 do not show any relevant negative anomaly, they do so in the case of winter barley, with −32.5% in total production against the five-year average, composed by −12% in area and −23.7% in yields (European Commission – Eurostat, 2017): in this case the AOC analysis captures the barley conditions better than wheat. In Poland 2015, production results +19% above the five-year average. In July 2015 the MARS AOC analysis reported damages to storage organs. Such analysis result in line with the yield statistic (−13%), but in contradiction with 2015 MARS yield forecast that reported only reduced yield expectations from favorable to average (European Commission – DG JRC, 2015a, 2015b). In Germany, the wheat loss for 2015–2016 season is very limited (−2.2%), while the impact is much more evident in rapeseed production (−9%) (European Commission – Eurostat, 2017). This result is in line with the regional distribution of AOC meteorological events that mainly covered the *Mecklenburg-Vorpommern* region, the main rapeseed-producing region with 20% of the national production. On the contrary, wheat is much more distributed and regions with no impact could have compensated for the ones that have suffered impact on production. In 2015–2016 in Italy, the production loss (−5.2%) is driven by a reduction of the harvested area (−8.8%) and there are no indications that such reduction depends on agro–climatic variables. In

support to this consideration, a general decrease of the soft wheat acreage is observed since the last years: the average of the previous five years constantly decreased from 6.16 Mha in 2010 to 5.79 Mha in 2016. Indeed, AOC just reported some unfavorable weather events during spring.

In the *SWL* class Italy – season 2014–2015 – and France – season 2015–2016 – are present. In Italy, the 2014–2015 producing season presents just a small reduction in overall production. The same considerations presented above for 2015–2016 season are valid for the season 2014–2015, but on top the AOC crop map marked one impact in May and one in June that moved 2014–2015 from MWL to *SWL* class. Those events were localized in a macro region (*Sud*) that produces < 8% of the national production (average 2010–2014), and thus the effect on national production can be neglected. In France, 2015–2016 winter wheat production was the lowest since 2000. The AOC analysis for that period is in line with the analysis of Zampieri (Zampieri et al., 2017) and other press sources (Agriculture, 2017; Agrimoney, 2017; AHDB, 2017; World Grain, 2017) in terms of damages from reduced radiation and over-wet conditions.

4.2. Grain maize based assessment

Table 5 presents the anomalies of the statistics, computed against the previous five-year average, and the *WI* values computed for winter wheat, for each country-year combination.

In Fig. 4, the results of the evaluation of AOC analysis for grain maize are presented.

In Fig. 4, the 20 strongest positive anomalies (production anomaly > +10%) are mostly classified in the LWL class – 12 points – as expected, while 7 and 1 points are classified in the MWL and SWL class. The strongest negative anomalies are distributed with 4, 7 and 7 points in the classes LWL, MWL and SWL, respectively.

The *LWL* class contains four out of five evaluations for Poland. In 2012, Poland almost doubled the grain maize production, compared to the five-year average, thanks to the sharp increase of harvested area that moved from an average of 202 Mha for the years 2007–2011 to an average of 620 Mha for the period 2012–2016 (Eurostat). Nevertheless, the four seasons classified as *LWL* – 2011–2012, 2012–2013, 2013–2014, 2015–2016 – present positive yield anomalies (> +5%).

The points with negative production anomalies classified within the *LWL* mostly belong to Mediterranean countries. In Spain and Italy, the 2015–2016 season presents negative production anomalies associated to a low level of warning. The negative production anomalies are related to a reduction of the harvested area: −11% and −26%, respectively, while yields present average to positive anomalies (+0.7, +10.3). In Greece, average and negative production anomalies of the 2011–2012, 2012–2013 and 2013–2014 seasons are explained with a decreasing trend in maize acreage (0.23 Mha in 2009 decreased to 0.15 Mha in 2016), but not with suboptimal weather conditions; as the positive yield anomalies for the three seasons (+2.3, +7.6, +0.1) confirm. Reduction of grain maize area is present in the last years for the Mediterranean countries: such trend is related to the increasing cost for maize production, often related to increased irrigation demand ("Federazione Coldiretti Lombardia,", 2016; USDA – FAS, 2017). Irrigation plays a relevant role in impact mitigation of suboptimal summer weather (Hawkins et al., 2013; van der Velde et al., 2010) and the AOC analysis considered it. In Spain, the season 2011–2012 is classified within the *LWL* class even if continuous drought occurred: the crop impacts were reported only for June and July and but in August. This latter month is the most sensitive for maize, as grain filling usually take place, but AOC analysis considered that possible damages were mitigated by irrigation, as visible by the positive yield anomaly (Table 5). At the same time, the presence of crop impacts in June and July was justified by impact on sunflower production, usually not irrigated, that decreased by 30% vs. the five-year average (European Commission – Eurostat, 2017). Sunflower season in august is at its end, as

Table 5
For each country (lines) – season (column) combination are reported, the anomalies of area (A%, top-left), yield(Y%, top-right) and production (P%, bottom-left) as well as the values of the WI (bottom-right), calculated for grain maize. Anomalies are expressed in percentage as the difference against the previous five-year average. In shade of red are highlighted the negative anomalies, in shade of green the positive anomalies, yellow colour represents around the mean anomalies. Darker the shade of the colour, stronger the anomaly. No highlight is proposed for the WI values.

A(%) / P(%)	Y(%) / WI	2011/2012		2012/2013		2013/2014		2014/2015		2015/2016	
AT		14.22	1.71	-0.09	-23.93	6.21	6.98	-10.65	-14.28	-6.47	12.52
		15.91	0.92	-24.11	0.72	13.43	0.72	-23.70	0.40	4.63	0.85
BG		51.08	-15.41	19.15	33.31	7.69	46.54	22.79	-7.33	-7.58	-3.54
		18.82	0.39	58.61	0.91	56.81	0.61	13.79	0.66	-10.96	0.45
DE		12.32	5.76	0.79	-11.65	-1.45	9.05	-7.38	-11.25	-14.97	-3.15
		20.74	0.87	-10.62	0.87	7.92	0.73	-18.72	0.30	-16.99	0.67
ES		10.62	12.74	23.34	8.60	12.30	6.25	2.93	5.84	-11.01	1.86
		16.18	0.94	28.71	0.99	18.45	0.79	6.45	0.34	-10.33	0.81
FR		5.23	-4.65	10.12	-14.09	9.54	9.41	-4.72	-6.91	-15.63	-10.52
		2.87	0.99	-2.36	0.99	21.99	0.74	-13.31	0.54	-24.27	0.47
GR		-10.58	2.31	-10.49	7.59	-17.23	0.14	-14.55	-9.99	-10.92	-9.50
		-8.15	1.00	-3.19	1.00	-16.79	0.88	-23.12	0.61	-19.65	0.72
HU		3.46	-41.83	5.85	-10.65	0.62	37.64	-3.43	-2.98	-15.73	48.58
		-32.79	0.59	-6.59	0.79	36.89	0.70	-7.39	0.38	23.10	0.93
IT		0.01	-10.73	-5.51	-12.28	-7.88	20.43	-22.23	13.31	-26.21	9.47
		-13.82	0.69	-9.93	0.64	10.05	0.83	-18.50	0.31	-18.31	0.82
PL		78.79	9.83	70.39	6.64	61.51	5.01	33.85	-26.48	4.49	17.62
		106.83	0.97	69.26	0.87	58.13	1.00	-6.57	0.57	20.29	0.78
RO		13.85	-35.82	3.23	27.23	2.36	26.12	4.70	-15.01	-0.31	7.12
		-26.39	0.39	32.89	0.72	30.33	0.61	-10.16	0.40	7.57	0.57

consequence no impact was remarked in the AOC map.

In the *LWL* class, there are cases where the AOC analysis missed to report unfavorable conditions that where correctly presented in the bulletin and yield forecast analysis. This is the case of the 2012–2013 season in France and Germany, which presents negative production anomalies but no relevant AOC events. In France, unfavorable over-wet conditions occurred during spring, while for Germany a lack of precipitation was present in early summer (European Commission – DG JRC, 2013a, 2013b). The two events were not considered critical or, since just partially covered the countries' territory, were considered not relevant at country scale. Hungary and Austria are present with negative production anomalies – –6.6% and − 24.1% respectively – in the *LWL* class for the 2012–2013 season. The unfavorable production is the result of hot weather affecting crops during August and this caused a sharp decrease in yield, as confirmed by other analysis (Strategie Grain, 2013). In this case, the AOC correctly reported the event but, by definition, did not provide information about the intensity of the damage.

The *MWL* class presents an equal distribution of points having positive and negative anomalies. Among those with positive anomalies, five points out of eight belong to the 2013–2014 season. That season presented a wet and a colder-than-usual summer, without any relevant impact for maize in most of the European countries. The AOC correctly reported no crop events but just some meteorological concerns. Among the points with negative production anomalies, two relate to the 2012 drought: Hungary (−32.8% in production) and in Italy (−14.0% in production). The AOC analysis for 2011–2012 season gave the right indications and reported the prolonged summer drought without a specific crop impact, because of the methodology used in 2011–2012, as already reported for winter wheat. A moderate warning was given for production in France, Greece and Poland for the season 2014–2015. France and Greece have seen a reduction in both yield and area due to the hot and dry summer conditions, while the drought in Poland was very intense (−26.5% in yield) compensating for the area increase (+33.9%). In the three cases, the AOC analysis caught the weather dynamics and their effect at the moment of the strongest intensity – August.

Indeed, during summer 2015 the lack of precipitation and high temperatures strongly damaged grain filling processes (Łabędzki and Bąk, 2017). AOC analysis highlighted the lasting drought hazard and its damages at the moment of their strongest intensity, August, but underestimated its early impact in June and July.

In the *SWL* class, two points out of ten present positive anomalies: Bulgaria (2011−2012) and Spain (2014–2015). Grain maize in Bulgaria registered a significantly increased harvested area: it shifted from an average of 309Mha in the period 2007–2011 to an average of 442Mha of the period 2012–2016. In 2012, Bulgaria recorded +18% in production thanks to the area extension, but yield anomalies for the same year result around −16% compared with the five years average due to the severe drought (Popova et al., 2014), in line with the AOC analysis interpretation. In Spain, the season 2014–2015 presents repeated heat wave along the summer: irrigated crops like maize did not suffer a drought impact, while not-irrigated crops, like sunflower, did (−16% in production). Summer 2015 was a peculiar year for almost all of the analyzed countries with eight out of ten that suffered from production losses and five that are classified in the *SWL* class. Romania, Hungary, Austria, and Germany present negative yields anomalies as a consequence of the dry and hot weather: the AOC analysis marked a repeated impact on summer crops development from flowering to harvest. In Italy, crop impact events were mapped as well, but the weather conditions were mitigated thanks to irrigation (yield +4.6%) and the production losses are related to the reduction in harvested area (−26%) only. In the *SWL* class, is correctly place the 2011–2012 season for Romania, affected by persisting drought.

5. Discussion

The AOC maps synthesize the available information within a defined period of analysis with respect to weather conditions and their possible impact on crop growth conditions. The analysis is done based on guidelines (indicators, thresholds), but the final decision of delineating an event is expert knowledge driven. The paper looks at the potential of the maps to

issue reliable warnings, with regards to decreases in crop production, based on delineated crop impacts. The tacit knowledge of the team of current MARS analysts was translated into a warning index (see 3.2) attributing to each ABS a specific contribution for the final production. This approach represents the first attempt to formalize the tacit knowledge within the group of MARS analysts. It could help to improve the consistency between the observed crop growth conditions, weather data and remote sensing information, and their interpretation done by the MARS analysts. For example, adverse weather conditions at harvest are often observed, but they are not translated into a crop impact, despite the expert knowledge attributes a relatively large importance to it in some of countries, e.g. the UK with 20% ($a_2 = 36°$) of contribution to the final production (Fig. 2). This miss match reveals a tendency of the analysts to underestimate unfavorable weather conditions at harvest or overestimate crop recovery capabilities around harvest. Crop events related to flowering, in spite of its relevance in the AOC assessment, present a low number of occurrences: a total of four events for winter crops and three for summer crops against > 50 meteorological events marked in June and July, for all the years. An explanation could be that flowering lasts only a relatively short period and, usually, a few days of difference in the flowering assessment determine if a relevant meteorological event has compromised flowering or not. In front of such difficulties, the AOC approach is often conservative and if no clear evidence of an impact is present in our data, impact on flowering tends to be underestimated in favor of a subsequent impact on grain filling.

In this paper, the AOC analysis is evaluated against national crop production statistics under the assumption that if an event is reported in the AOC maps it should have relevance at country level for the crop production. Nevertheless, there are cases in which unfavorable crop conditions at regional level could be compensated by favorable conditions from other regions, like the case presented for Germany, season 2015–2016. Winter wheat was impacted at regional level (*Mecklenburg-Vorpommern* region −20% of winter wheat regional production against five-year average) but it was compensated by production surpluses in other regions. The AOC analysis could thus provide valid information about regional trends which are not explicit in the yield forecasting at national level. Regional crop yield forecasting is part of future developments of the MCYFS, but the AOC analysis already provides qualitative information about the most relevant regions, as does the country analysis text of the JRC MARS Bulletin.

However, the comparison of the issued warning level per country via the AOC maps (weather and crop impacts) with production anomalies revealed some good agreements (e.g., France, serious warning level for the season 2015–16 for winter wheat).

In its qualitative approach, the AOC analysis doesn't provide any distinction among the different intensity that the same crop event could have produced in different regions or in different years. Addressing this point would represent a significant advance in the AOC analysis moving it from purely qualitative to a more quantitative assessment.

Also the AOC methodology does not present crop specific information. Nevertheless, some crop specific information is implicit due to the predominance of a given crop in a certain region: as the reported cases for Germany and Italy about rapeseed and durum wheat. Such information is actually not provided to the public and it depends on the readers' knowledge and their ability to link general information to a crop specific context. How to realize synthetic products reporting even on crop specific information is an open question.

The comparison between the results about winter wheat and maize highlighted that maize dynamics are much more influenced by area changes. This is evident in the Mediterranean regions, where inter-annual production variability responds to changes in the area, which is more linked to climate and economic dynamics, than seasonal weather, often mitigated thanks to irrigation and management activities.

The AOC maps are already considered – by stakeholders, information providers, and dedicated media – a relevant synthesis tool as demonstrated by several publications that cite or reproduce the AOC maps. To maximize the capability of the AOC analysis, an effort would be required (1) to formalize as much as possible the tacit knowledge of each analyst and to make it available. (2) To find ways to include regional and crop specific information, without losing the synthetic capability. This latter point could result of specific interest because would trigger an effort in automatizing the analysis process – due to the large number of regions that should be considered. The automation process could be sustained by artificial neural network trained with past AOC map elements that could be linked with quantitative data, in order to obtain an automatic set of weather and crop map. Such study would need to re-assess all the past potential AOC that were not considered relevant, according to the analyst. From another point of view, the definition of the WI and its components (ASB) computed for this paper represents an interesting starting point to increase the informative content of the AOC analysis, providing, instead of impact description only, a qualitative warning level assessment, probably directly digestible from not-expert readers.

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