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Strengthening agricultural decisions in countries at risk of food insecurity: The GEOGLAM Crop Monitor for Early Warning

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1. Introduction

1.1. The need for reduced uncertainty in crop assessments for countries at risk of food insecurity

According to the United Nations' *2018 Food Security and Nutrition in the World* report, the number of undernourished people worldwide increased for the third year in a row in 2017, reaching 821 million (FAO et al., 2018). Prior to 2014, this figure had been on the decline and this recent slow in hunger reduction jeopardizes the United Nations' goal of eradicating hunger by 2030, as specified in the United Nations 2030 Agenda for Sustainable Development, particularly Sustainable Development Goals (SDG) 2: Zero Hunger. While there are numerous factors contributing to the increase in global hunger, the main drivers include climate variability and climate extremes leading to acute food crises (Ray et al., 2015). Existing literature suggests climate change will exacerbate nutrient deficiency among those populations already most vulnerable to food insecurity (e.g. Wheeler and Von Braun, 2013; Schmidhuber and Tubiello, 2007). According to a recent report of the Global Commission on Adaptation (Bapna et al., 2019) out of 5 investment areas with the highest potential return for climate adaptation, Early Warning Systems are the area with the highest benefit-cost ratio (10:1). Unfortunately adaptation to climate change is challenging in environments characterized by the predominance of low yielding varieties, limited access to inputs (seeds, fertilizer, etc.), and lack of irrigation infrastructure. In these same environments, human and instrumental networks necessary for timely climate hazard and crop monitoring are not fully in place, which adds the risk of tardy detection

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and delayed response to that of the agricultural vulnerability. In the absence of established in situ networks for monitoring crop conditions locally, Earth observations (EO) data provide an affordable, reliable, and timely source of data which can be used as indicators of crop conditions and production across spatial and temporal scales (Rembold et al., 2010).

There are several organizations and agencies that independently monitor crop conditions at a national, regional or international scale, with the goal of providing early warning of food production shortages, each utilizing a unique combination of assets that include ground observations, remote sensing, models, and a network of cooperators and informants for their respective regions of interest. The purpose of these early warning systems is to prompt early response and address a crisis before it manifests, which in turn requires the dedication of substantial resources. Due to the financial cost of invoking such a response, decision makers rightfully demand compelling evidence before making such commitments.

There is considerable geographic overlap among these monitoring systems. However, due to the gaps in geographic coverage, mandate and methodological differences between systems, discrepancies in crop conditions reported by different agencies and organizations often occur. This ambiguity reduces decision makers' confidence in the evidence and inhibits the decision to mount a response. The more unambiguous an early warning can be, the more effectively it will elicit early response. Therefore, early warning systems must maximize the use of available observational evidence, experience, and judgement and international development and aid donors are asking for joint multi-stakeholder and harmonized early warning information (e.g.: http://www.fsincop.net/global-network/about/en/).

Working under the Group on Earth Observations Global Agricultural Monitoring initiative (GEOGLAM; Group of 20 Agriculture Ministers, 2017), international, regional, and national crop monitoring organizations came together to build the Crop Monitor for Early Warning (CM4EW), (http://www.geoglam.org/index.php/en/countries-at-risk-en) relying largely on earth observations data and demonstrating the value of these data in an operational setting in support of food security decisions. The CM4EW is a community activity based on common goals, and characterized by sharing data, information, networks, and experience. Using common definitions and criteria for crop monitoring, members of the CM4EW community build consensus on crop conditions globally through a monthly deliberative process with a focus on improving food security. This framework leverages existing resources while reducing the ambiguity of the information provided to decision makers through a convergence of evidence, harmonization, and consensus building approach, filling information gaps within the agencies and organizations but also resulting in a monthly univocal assessment of food availability.

1.2. Relevance to the UN sustainable development goals

Agricultural monitoring and early warning, as provided by the CM4EW initiative and its products, cut across several of the goals and targets outlined in the United Nations 2030 Agenda for Sustainable Development, the most obvious intersection is with Goal 2: Zero Hunger. The products produced through the CM4EW activity address target 2.1:"by 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round" (United Nations, 2015a) by providing science-driven and actionable information on current crop conditions to better inform government and humanitarian organizations' response to food insecurity. Additionally, CM4EW acts as an early warning tool to reduce vulnerability and increase resilience, as is cited in Goal 3: Health and Well Being under target 3.D and in Goal 13: Climate Change, under target 13.3 by improving institutional capacity towards impact reduction and early warning. The CM4EW indirectly supports Goal 1: End Poverty, target 1.5, through reducing vulnerability to climate-related extreme events and other economic, social and environmental shocks. In this way, the CM4EW is contributing to the reduction of risk and the mitigation of human-costs associated with climate change, extreme weather events, and the associated impacts on crop production and food supply. Through early warning of drought and crop failure, as well as through enhanced reliability of crop assessments with cross-agency consensus, end users have the ability to predict the scale and extent of these events earlier in the season and trigger appropriate disaster response mechanisms (Brown et al., 2014; Enenkel et al., 2015; Kogan et al., 2015; Torbick et al., 2017). These include targeted monitoring, fast-tracking of planned crop assessments, annual vulnerability assessments, increasing off season production, and food mobilization efforts. With early warning triggering early action, governments can appropriately respond to events and offset damages and impacts to food security and population livelihoods in advance of disaster (Food and Nutrition Security Working Group, 2018; Office of the Prime Minister Uganda, 2018).

1.3. Establishing the CM4EW

The CM4EW was launched by GEOGLAM following the development and implementation of the Crop Monitor for the G20 Agricultural Market Information System (AMIS) (Becker-Reshef et al., 2019). GEOGLAM and AMIS were both endorsed in 2011 by the G20 Agriculture Ministers as part of the Action Plan on Food Price Volatility and Agriculture with the aim to increase information availability, quality and transparency (Group of 20 Agriculture Ministers, 2011). The action plan's assumption is that crop condition information from Earth observations would help provide objective, timely information to the markets and through this increased transparency help attenuate food price spikes. With its focus on global markets, the Crop Monitor for AMIS, initiated in 2013, focuses on the four major commodity crops (wheat, maize, soybeans and rice) within the major production and export countries, providing an international monthly consensus on crop condition.

Based on the success of the Crop Monitor for AMIS and recognizing that there was an even more pressing need for enhanced, reliable, vetted information on crop conditions in the countries most at risk of food insecurity, its methods were adapted to launch a parallel effort, the CM4EW, focused on countries-at-risk of food insecurity (Fig. 1). Under the auspices of GEOGLAM, USAID FEWS NET, EC JRC, UN WFP, UN FAO, and the University of Maryland the CM4EW was initiated in 2016. Consistent with the missions and objectives of the founding organizations, the goal of the international CM4EW was to provide transparent, multi-sourced, consensus assessments of the crop growing conditions, status, and agro-climatic conditions that are likely to impact production in countries vulnerable to food insecurity in order to strengthen agricultural, humanitarian intervention, food security decision making and policy implementations. These crop assessments were developed to be straightforward and targeted towards operational audiences including: the CM4EW partner organizations themselves, which represent the primary humanitarian organizations concerned with food security (described further in Section 2), governments, NGOs and media.

2. Methods: crop monitor partners and process

The CM4EW builds largely on the existing regional and global-scale crop monitoring systems operated by the main agencies mandated to assess crop conditions and production worldwide within the context of early warning and food security. These operational agricultural monitoring systems include the FAO Global Information and Early Warning System (GIEWS, http://fao.org/giews), the FEWS NET Data Portal (https://earlywarning.usgs.gov/fews), the World Food Program Vulnerability Assessment system (VAM), China CropWatch (Wu et al., 2010; Wu et al., 2014; Wu et al., 2015) from Chinese Academy of

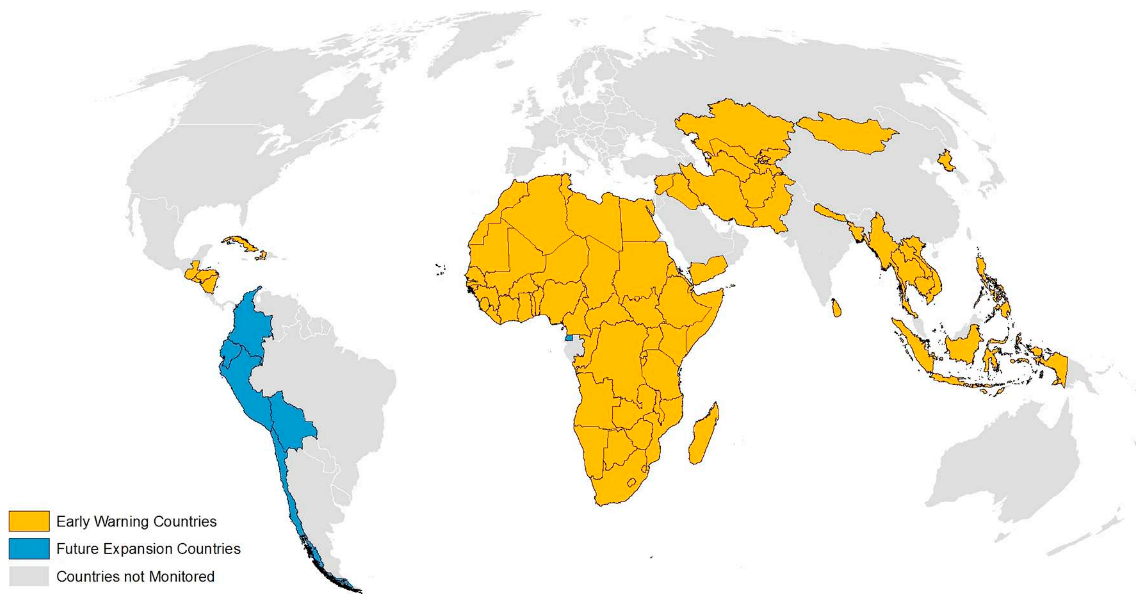


Fig. 1. Countries currently covered by the CM4EW's reporting and target countries for future expansion, as of November 2018.

Sciences' Institute of Remote Sensing and Digital Earth (CAS RADI), Crop Explorer (https://ipad.fas.usda.gov/cropexplorer) from the US Department of Agriculture (USDA), and the JRC Monitoring Agricultural ResourceS (MARS) system (https://mars.jrc.ec.europa.eu/asap/). As described by Fritz et al. (2018), these aforementioned global monitoring systems have largely operated without a common platform for developing consensus and reducing uncertainty regarding crop conditions in regions at risk of food insecurity on an operational basis. The same review paper concludes that while there are many methodological similarities among the major operational systems, each of them is tailored to meet the needs of their specific stakeholders and therefore prioritize different input data, methodological aspects, and outputs dissemination strategies. Many of these systems can still be improved in several key aspects, including increasing the exploitation of more systematic and operational high resolution satellite imagery, implementation of crowd-sourcing approaches to increase the availability of ground data, utilizing more consistent calibration and validation methods, as well as improving coordination and information sharing across these systems.

The majority of the global crop monitoring systems mentioned above contribute regularly to the CM4EW, in addition to regional and national partners. (Table 1). These partner organizations are at the core of the CM4EW in terms of the methods and processes adopted, as well as in terms of the information they provide through their individual organizations, which collectively form the CM4EW products. It is the variety of data sources used by partner organizations (Table 2) and the differences, discussions, convergence, and consensus building surrounding these assessments that form the value added by the unique community forum that is the CM4EW. The convergence of evidence allows analysts to question each others' analysis and jointly build a strong, science driven case for current condition classification and assessment of potential impacts to production (as exemplified by the case study of Southern Africa in Section 4.1), strengthening the case for early action by national governments and humanitarian organizations to support vulnerable communities. In this context of increasing transparency and facilitating global dialogue on crop conditions as they impact food security, the CM4EW is additionally able to support the attainment of SDG 2.1, and targets 3.D, 13.3, and 1.5 as described in Section 1.2. That is, the primary objective of the CM4EW is to support regional and national level information end users through the provision of actionable information on drought and disaster for early warning, but the UN and others acknowledge that in order to be successful, the SDGs should – wherever possible – identify, leverage, and maximize the value of complementary and overlapping activities (Pradhan et al., 2017; United Nations, 2015b).

2.1. CM4EW partner organizations information sources

The partner organizations of the CM4EW often rely on a strong network of regional analysts whose expert knowledge is used to derive meaningful information from ground observations, satellite-derived vegetation indicators, models, and agrometeorological data. Though the data used often overlaps, each partner brings a unique analysis approach based on differences in perception, information sources, information access, expertise and judgement. Where these differences arise, a discrepancy often occurs, as outlined in Section 2.4.

Earth observations provide detailed, spatially-explicit information, which are a key asset for agricultural monitoring, particularly in areas where access to field information is limited and smallholder subsistence agriculture dominates (Enenkel et al., 2015; Funk and Verdin, 2010). This is the case for many of the countries most at risk of food insecurity wherein limited funds, capacity and, in some cases, conflict prevent regular field assessment operations and reporting. Agrometeorological and remote sensing information are often the first and even the sole source of information on crop conditions, allowing rapid and large scale assessment of potential weather related impacts on agricultural production (Wu et al., 2015; Becker-Reshef et al., 2010; Becker-Reshef et al., 2019; Funk et al., 2015; Brown et al., 2015; Senay et al., 2013; Rembold et al., 2010). These data sets are often used to identify anomalies that can be associated with potential agricultural impacts and are used together to provide a robust basis for convergence of evidence of agricultural conditions, which is especially useful when field reports are unavailable (Table 2).

While EO allow important insight into crop development and conditions, field information and national reports provide validation and enable more in-depth analysis. FAO, WFP, and FEWS NET all have regular field missions to target critical areas, which allows for access to field verification and assessment of crop condition. These field assessments provide primary data to verify and calibrate Earth observation data, further enhancing the use of remote sensing analysis for agricultural monitoring. In addition to these assessments, national reports on market prices and trade information, which provide indications about production expectations, are closely monitored by partners such as FAO and FEWS NET to further inform food security prospects. The

Table 1
The CM4EW partners and their associated regions of interest for crop condition reporting.

CM4EW partner agency	Division	Regions of interest	Website
United States Agency for International Development (USAID)	Famine Early Warning System (FEWS NET), Office of Food For Peace (FFP)	Central and South Asia, East Africa, West Africa, Southern Africa, Central America and the Caribbean, Yemen	http://fews.net/
United Nations World Food Programme (WFP)	Analysis and Trends Service	Near - Global	http://dataviz.vam.wfp.org/seasonal_explorer/rainfall_vegetation/visualizations https://www.wfp.org/content/seasonal-monitor
European Commission (EC)	Joint Research Center (JRC)	Middle East and North Africa, East Africa, West Africa, Southern Africa, DPRK	https://ec.europa.eu/jrc/en
United Nations Food and Agriculture Organization (FAO)	Global Information and Early Warning System (GIEWS)	Global	http://www.fao.org/giews/en/
GEOGLAM	Asian Rice Crop Estimation & Monitoring (Asia RiCE)	Southeast Asia	http://www.asia-rice.org/ https://suzaku.eorc.jaxa.jp/cgi-bin/gcomw/jasmine/jasmine_top.cgi
Intergovernmental Authority on Development in Eastern Africa (IGAD)	Climate and Prediction Application Centre (ICPAC)	East Africa	http://www.icpac.net/
Agriculture Research Council (ARC)	Geoinformation Science	South Africa	http://www.arc.agric.za/Pages/Home.aspx
Applied Geosolutions		Southeast Asia	http://www.appliedgeosolutions.com/
Uganda Office of the Prime Minister (OPM)	Department of Relief, Disaster Preparedness and Management (DRDPM)	Uganda	https://opm.go.ug/disaster-preparedness-and-management/
Tanzania Ministry of Agriculture Livestock and Fisheries (MALF)	National Food Security Division (NFSD)	Tanzania	http://www.kilimo.go.tz/index.php/en/

integrated use of these information sources is crucial to the CM4EW process and for resolving discrepancies in assessments across agencies.

2.2. CM4EW process

The CM4EW bulletins report monthly crop conditions at the sub-national scale for the countries most at risk of food insecurity. Each bulletin is published following an established reporting and consensus-building process. During the final ten days of each month, the Crop Monitor online interface is opened and regional analysts from the partner organizations submit their crop assessments over their regions of interest (Table 1).

The partners input current crop conditions based on a suite of information sources including satellite observations, meteorological information, field observations, and ground reports from their respective organizations and contacts. For each sub-national area/crop combination for which an analyst is responsible and for which the target crop is in season, the analyst will enter the crop's condition and associated drivers of the condition (Tables 3 and 4). On average, close to seven hundred entries are submitted each month into the CM4EW system. Crop condition classes are defined with respect to expected yields over a sub-national region as compared to the five-year average and include conditions of “exceptional”, “favourable”, “poor”, and “failure”. This classification system is based off the Crop Monitor for AMIS system (Becker-Reshef et al., 2019) but with an additional “failure” class to address a situation more common in early warning countries where crop yields are likely to be 25% or more below the average (Table 3). Even though production is of ultimate interest, classifications are made considering prospects for yield. This is due to the current limitations for detecting changes in cropped area in near-real time in landscapes dominated by smallholder cultivation. In cases where conditions are classified as other than favourable, the primary drivers for these conditions are provided (Table 4). The classification scheme was developed with the recognition of the varying drivers of current crop condition across the early warning target countries. These represent the key climatic as well as socio-economic drivers that are impacting crop conditions and can act as either positive or negative drivers of crop conditions.

Following the ten-day assessment period, the GEOGLAM Crop Monitor Coordination team at the University of Maryland, on behalf of the GEOGLAM Secretariat, compiles the analyst-submitted crop conditions into summary and discrepancy maps. These maps are sent out to analysts for review and a conference call is held with all partners to discuss and review discrepancies over all reporting areas. The conference call is a central step that allows partner organizations to share and discuss discrepancies in reporting and come to an agreement on

Table 2
Information sources used by the CM4EW partner organizations in their monthly crop condition assessments.

Information Sources		WFP	USAID FEWS NET	EC JRC	FAO GIEWS	Asia Rice	ICPAC	ARC
Agro-meteorological	Precipitation	X	X	X	X	X	X	X
	Temperature	X	X	X	X	X	X	X
	Evapotranspiration	X	X	X	X	X	X	X
	Snow water volume		X	X	X			
Remote Sensing	Vegetation Indices	X	X	X	X	X	X	X
	Soil Moisture	X	X		X	X	X	X
	Drought Indices	X	X	X	X	X	X	X
	Very high to high resolution optical imagery		X	X				X
Models	WRSI (Senay et al., 2015)				X	X		
	ASAP (Rembold et al., 2018)			X	X			
	ASIS (Van Hoolst et al., 2016)				X			
Field information			X		X		X	X
National/Regional information sources		X	X		X	X	X	X
Media mining		X		X	X			

Table 3
Crop condition classification scheme. Note that 'average' refers to conditions relative to the most recent 5-year period.

Condition name	Condition color	Definition
Exceptional		Conditions are much better than average at time of reporting. This label is used only during the grain-filling through harvest stages.
Favourable		Conditions range from slightly below to slightly above average at reporting time.
Watch		Conditions are not far from average but there is a potential risk to final yields. There is still exists the time and the ability for the crop to recover to average conditions if the ground situation improves. This label is only used during the planting-early vegetative and the vegetative-reproductive stages.
Poor		Crop conditions are well below average. Crop yields are likely to be 10–25% below average. This is used when crops are stunted and are not likely to recover, and impact on yields is likely.
Failure		Crop conditions are extremely poor. Crop yields are likely to be 25% or more below average.

Table 4
Drivers that represent the key climatic drivers that are having an impact on crop condition status. These drivers can result in yield impacts and can act as either a positive or negative driver of crop conditions.

Driver name	Driver icon	Definition
Wet		Higher than average precipitation or saturated soil conditions.
Dry		Drier than average.
Hot		Hotter than average.
Cool		Cooler than average or risk of frost damage.
Extreme Events		This is a catch-all for other climatic risks (i.e. hurricane, typhoon, frost, hail, winterkill, wind damage, etc.).
Delayed -Onset		Late start of the season.
Pest & Disease		Destructive insects, birds, animals, or plant disease.
Socio-economic		Social or economic factors that impact crop conditions (i.e. policy changes, agricultural subsidies, government intervention, etc.).
Conflict		Armed conflict or civil unrest that is preventing the sowing, working, or harvesting of fields by the famers.

current crop condition and drivers based on the best available information. This process results in the consensus assessment of all crop conditions and drivers (as shown in Fig. 3) published in the CM4EW monthly bulletin.

2.3. Baseline datasets

The CM4EW is built utilizing a foundation of several core datasets in order to monitor monthly crop conditions in areas-at-risk around the world. GEOGLAM and its community of practice play a role in EO data coordination by consistently acquiring data sets relevant to agricultural monitoring, processing the data sets to ensure continuity, and providing access to the data for partner organizations on the Crop Monitor interface (Becker-Reshef et al., 2019; Whitcraft et al., 2015a, 2015b). A general cropland mask is included to separate out the cropped areas from other land-use types to focus analysis on those areas that sustain crops (Fritz et al., 2015).

Meanwhile, sub-national administrative units provide the basic unit for analysis. These units are aggregated along cropland areas that have generally homogenous agro-climatic conditions. Across countries of interest, seven main food security crops (maize, rice, wheat, beans, cassava, millet, sorghum, teff, groundnut) along with one or two main crop seasons, as dictated by crop rotation practices, were chosen based on the population's main food sources and the ability to regularly monitor the chosen crops using EO data and field reports. For each of the chosen crops, crop stage calendars were developed based on USAID and FAO crop calendars. The calendars were then refined by regional crop analysts to represent the five-year average of the crop growth cycle within each sub-national administrative unit and generalized according to five broad classes (Planting through Early Vegetative, Vegetative through Reproductive, Ripening through Harvest, End of Season, and Out of Season). The calendars, masks, and sub-national administration units combined with EO-derived datasets form the baseline datasets and the necessary elements for the monitoring of croplands in early warning regions. These datasets facilitate a framework under which partner organizations can assess conditions and come together to discuss discrepancies in reporting as outlined in the following section.

2.4. Resolving discrepancies and developing a consensus

The key component of the CM4EW process is the development of consensus crop conditions within the Early Warning community in order to increase the evidence base and confidence in the assessments that support food security decisions. Each partner organization provides an independent analysis of crop conditions based on EO data, models, agrometeorological information, ground observations and expert knowledge (Table 5), with associated confidence level of assessments (Table 6). By design, there is overlap in the number of reporters for each region/crop combination (Fig. 2), and while they are generally consistent with each other in areas of mutual coverage, discrepancies in crop condition classification regularly occur. In particular, in countries where the number of reporters is high, the number of discrepancies will also typically increase, while in countries with a lower number of reporters, the number of discrepancies is generally lower. It should be also noted that there are more reporting partners over regions that have traditionally been more prone to food insecurity and often lack reliable information. In general, as the number of analysts per country increases, the confidence in the final consensus crop condition assessments increases, as a result of the independent coordinated assessments and consensus building process.

Discrepancies can arise when experts have different perceptions of

Table 5
CM4EW ranking of field and remote sensing sources of supporting evidence.

Verified Field Information	A qualified and recognized source has observed the condition class in the field
Reliable Field Information + RS	The condition class is reported from the field by a reliable source and is consistent with remote sensing products
Unverified Field Information + RS	The condition class is reported from the field by a source of unknown qualifications and is consistent with remote sensing products
Multiple Converging RS Products	The crop condition class is determined by a convergence of two or more independent RS products, though without supporting field information
Diverging RS Products	The crop condition class is determined by independent RS products with divergence of two or more among them, and no field information

Table 6
CM4EW analyst confidence level.

Very High	The analyst is very confident in the quality, timeliness and accuracy of the classification
High	The analyst is confident in the quality, timeliness and accuracy of the classification
Medium	The analyst is moderately confident in the quality, timeliness and accuracy of the classification
Low	The analyst is not very confident in the quality, timeliness and accuracy of the classification
Very Low	The analyst is not at all confident in the quality, timeliness and accuracy of the classification

the seasonality and crop stage in the assessed area. The rate of discrepancies is particularly high in countries/regions with complex interactions between weather and geography, where diverse rainfall patterns may exist even in nearby areas. As a result, experts, with information pointing towards the same assessment, can provide a different assessment if their reference cropping period is not the same. On the other hand, discrepancies may arise when experts share the same perception of the variations in the crop lifecycle due to delayed planting, late rains, etc. in the assessed area however, the information they possess and their judgement point towards diverse results. This is the most common cause for discrepancies and it may derive from the following underlying factors:

a) Experts use a variety of information sources: Experts often rely on multiple sources to gather information on weather conditions and crop performance, including reports prepared by various organizations and different remote sensing data and interfaces. In some instances, the various sources can provide discordant information and generate discrepancies between assessments.
b) Experts use of a variety of assessment procedures: Although some experts rely entirely on remote sensing data, others use both remote sensing data and reports from the ground, attributing more or less relevance to one of the two information sources.
c) Experts attribute a different degree of importance to the various drivers affecting crop prospects: In the same period and in the same area, some drivers have a positive impact on crop performance and support favourable prospects, while others have a negative impact and support unfavourable prospects. By attributing a different degree of importance to the various drivers, experts can perceive crop conditions and prospects differently.
d) Experts attribute a different impact of the drivers on the outcome of the season in terms of yields and output: Even considering the same drivers and according to them the same relevance, different experts may still have a discordant judgement about their impact and assess crop conditions differently in relation to the conventional thresholds of the CM4EW classification system.

These discrepancies necessitate the consensus-building process, which involves inter-agency sharing of data, evidence and expertise, leading to further collaborative analysis of crop indicators and field reports. Agreement on crop condition must be unanimous before it is published in the CM4EW bulletin. The monthly conference call is central to resolving discrepancies and building consensus by providing a forum for submitted conditions to be discussed and reviewed among partners. The source of evidence and the confidence level of the analyst (Tables 5 and 6) play a key role in the weights given to each agencies assessment and to resolving discrepancies. Generally, the number of discrepancies varies according to the number of crops in season for a given subnational unit as well as the potential for crop production shortfalls. For example, worsening crop conditions require special attention as the goal is to provide actionable information while simultaneously minimizing the risk of both raising false alarms and understating poor conditions. In general, the number of discrepancies per month ranges between 30 and 100, depending on which regions are in season, though some have reached as high as 140. Through an evidence sharing process, analysts discuss crop conditions and their associated information sources and work through discrepancies, weighing available supporting evidence and prioritizing field information from national sources and partners that can then be compared to and verified with remote sensing data sources. In areas without access to reliable and verifiable field information, priority is given to conditions with multiple sources of converging remote sensing-driven evidence. In countries where uncertainty is high and national contacts are available, analysts will follow up with national counterparts to verify information

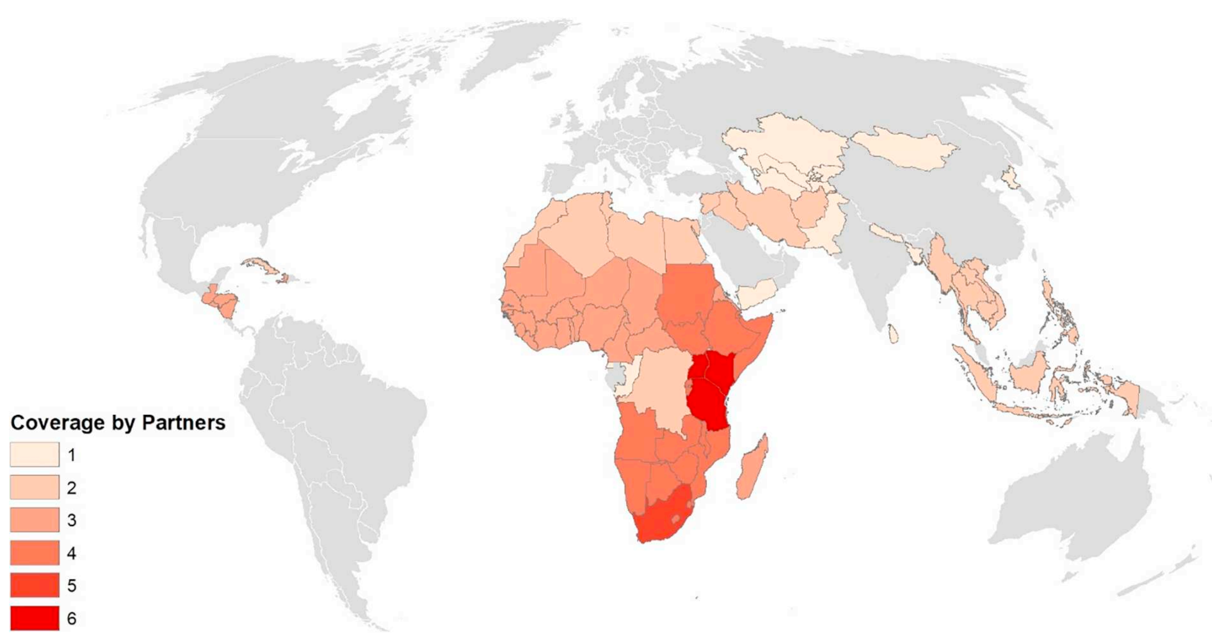


Fig. 2. Number of CM4EW partner agencies per Early Warning country.

sources and request confirmation. Through this consensus-building process and coordinated assessments, the CM4EW products reduce uncertainty and provide the best available information on current crop condition to better inform decision making at the regional and national scale in support of food security and livelihoods.

3. Results: The CM4EW bulletin

The primary output of the CM4EW initiative is the monthly Crop Monitor for Early Warning Bulletin containing the consensus crop condition assessments for each crop (and crop season) at the sub-national scale, with textual, map, and pie chart information delivery. As the CM4EW was designed to communicate consensus-based actionable information on current crop conditions to agencies concerned with food security, the presentation of information is designed for quick ingestion primarily by non-remote sensing users. The bulletins include a textual overview of conditions by region, summaries of special global climatic events such as El Niño or La Niña that may adversely affect crop production, and regional crop condition summaries. Textual information on regional crop conditions is supplemented by crop condition maps and production-based pie charts. Synopses of crop conditions and prospects are provided for each country and major crop. A topical regional climatic forecast is provided for areas at risk of production shortfalls and/or food shortages.

Drawing from the design work in the Crop Monitor for AMIS, synthesis maps show current crop conditions for multiple crops of interest in a given region. Condition maps (Figs. 3, 6, 7) indicate sub-national conditions as identified through the consensus-building process, which are then masked to highlight agricultural areas. To increase the level of detail, crop-specific maps provide context to the crop conditions through inclusion of the crop stage calendars.

Production-weighted pie charts (Fig. 3) indicate the relative significance of the area under different crop conditions as a proportion of the country's total production, based upon a 5-year average. Crops that are in less-than-favourable conditions are displayed in the chart along with icons indicating the key drivers negatively affecting the given crops. These charts were designed to communicate the relative importance of individual crop conditions in terms of total regional production.

4. Application of the CM4EW Bulletin to inform decisions

The following case studies provide narratives of the evolution of information and data availability as the season progressed, and the ways in which the CM4EW participating agencies worked together to develop a consensus on crop conditions and empower decisions throughout the seasons.

4.1. Southern Africa Case Study: early warning and early action for extreme events

Approximately 60% of people in the Southern African Development Community (SADC) rely on agriculture for subsistence food production, income and employment (SADC, 2013). With less than 10% of crop production in the region under irrigation, the majority of the population is vulnerable to the adverse effects that unfavourable precipitation conditions can have on crop production. In particular, maize, the staple food crop in most parts of the region, is vulnerable to long dry spells that can significantly reduce crop yields. These dry spells occur frequently in some areas, resulting in a relatively high risk of poor harvests. Given the high dependence of millions of people on agriculture for their livelihoods, poor harvests translate directly to high levels of food insecurity – on average, approximately 30 million people in the SADC region were assessed to be food insecure between 2014 and 2018 (SADC, 2018). These food insecure populations require food assistance that can usually be provided in a timely manner if early warning of impending reductions in crop harvests can be developed. Such early warning requires regular monitoring of seasonal progress using the best available data.

The 2015/2016 rainfall season in Southern Africa was one of the driest in over 35 years, with significant adverse impacts on agriculture and food security. The impacts were amplified by the preceding 2014/2015 season, which was also characterized by low rainfall. At the end of the 2015/2016 season, regional cereal production was 10% below the 5-year average, resulting in over 40 million food insecure people with 25.6 million of these in need of emergency food assistance (SADC RVAA, 2016).

The first indication of a potentially adverse 2015/2016 season was the El Niño advisory issued by the NOAA Climate Prediction Center (CPC) in February 2015, based on analysis of satellite-observed sea-surface temperatures and model forecasts (Climate Prediction Center, 2015). Historical rainfall data analysis has shown that El Niño is associated with a high likelihood of below-normal rainfall in many parts of Southern Africa. In June 2015, FAO (GIEWS) issued an analysis of the potential impacts on agricultural production, indicating possible reductions in cereal crop yields in Southern Africa (FAO, 2015). In addition, the FEWS NET Food Security Outlook released in July 2015 concluded that potentially late onset of rains associated with El Niño conditions could limit labor opportunities, thus worsening food insecurity in Southern Africa.

As early as November 2015, various EO-based datasets, including the normalized differenced vegetation index (NDVI; Tucker, 1979) – an indicator of vegetation greenness, which is commonly used as a proximity measure for vegetation health – were able to capture the negative impacts that climatic conditions were having on natural and cropped vegetation (Fig. 4). Although the vegetation index anomaly was only slightly negative in October, the severity of dryness gradually escalated between November 2015 and January 2016 (Fig. 4b, c and d).

The rainfall performance for the 2015/2016 season was one of the worst on record. An analysis conducted using the Climate Hazards Group InfraRed Precipitation with Stations dataset (CHIRPS; Funk et al., 2015) showed that for the period between 1 October 2015 and 20 February 2016, many areas received their lowest seasonal rainfall accumulations since 1981 (Fig. 5). This analysis was used by the CM4EW as well as in a variety of official statements and presentations to highlight the severity of the drought.

Other datasets and analysis including evapotranspiration, temperature and crop water balance modeling (Senay et al., 2013; Wan, 2007; Verdin and Klaver, 2002) corroborated the conditions portrayed by the vegetation indices and precipitation deficits. National reports, which provide critical field information, further corroborated many of the observations made using satellite- and model-based analyses. At the same time, the CM4EW was being prototyped and the developing droughts propelled its partner organizations to work more closely together to develop and launch this initiative, recognizing the importance of sharing data and information to increase the reliability of crop condition assessments and impacts on production and the need for international consensus to strengthen credibility.

In early February 2016, the inaugural issue of the Crop Monitor for Early Warning bulletin painted a grim picture of crop conditions in Southern Africa (Fig. 6), with negative implications for food security. Initially, there were close to forty discrepancies between the crop condition assessments shared between the partner agencies over Southern Africa alone (Fig. 7), demonstrating the high uncertainty and the clear need for sharing information and analysis during this critical time. The information released by the first issue of the CM4EW bulletin served to corroborate national and regional reports on the developing crisis, bringing visibility and credibility to the new initiative.

Following the publication of the first CM4EW bulletin, its four key partners at the time, the WFP, UN FAO, FEWS NET, and the EC JRC, released a joint statement in early February 2016, entitled “El Niño Set to Have a Devastating Impact on Southern Africa's Harvests and Food

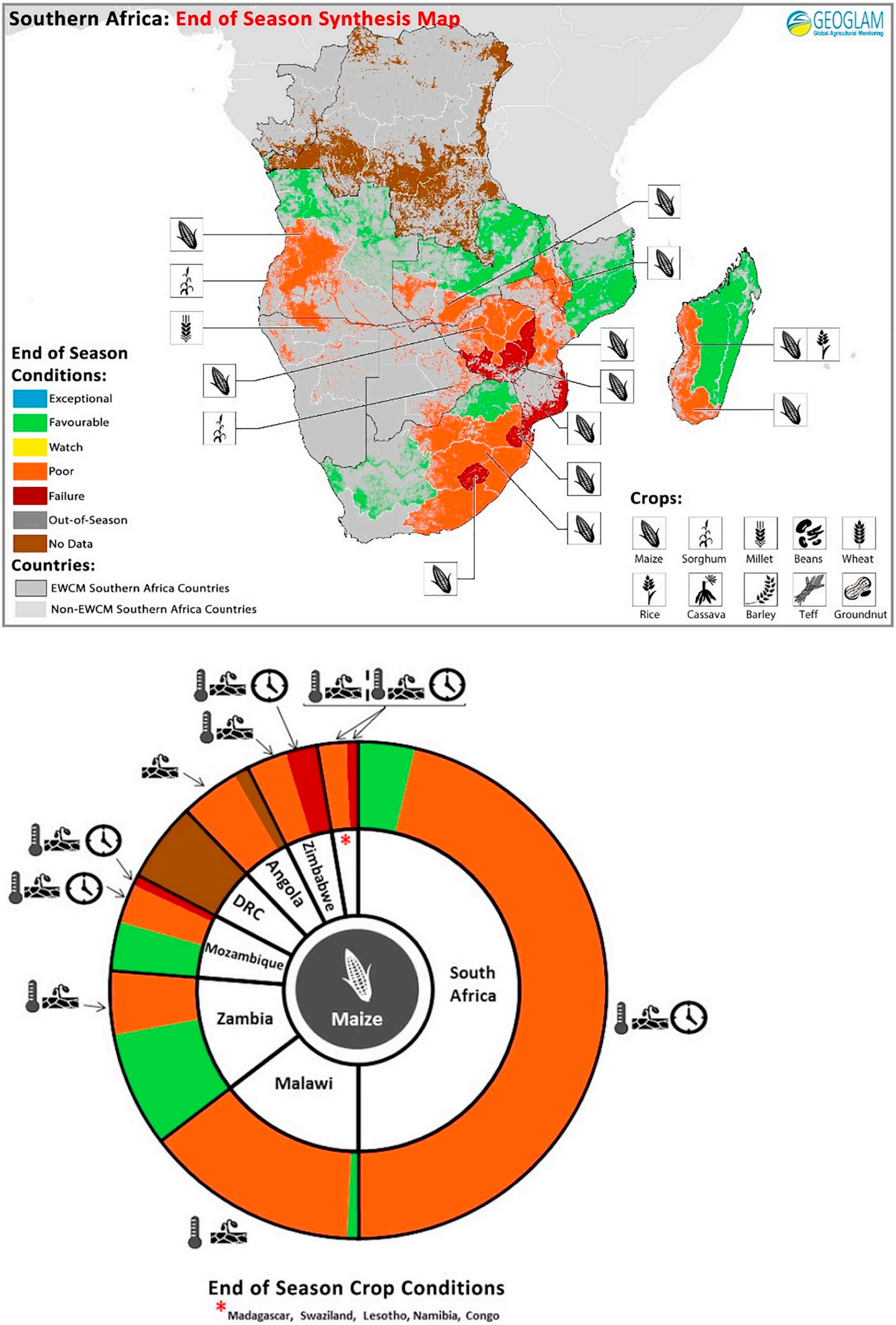


Fig. 3. Post-harvest crop conditions at the end of the 2015/2016 maize season in Southern Africa displayed in map and pie chart formats.

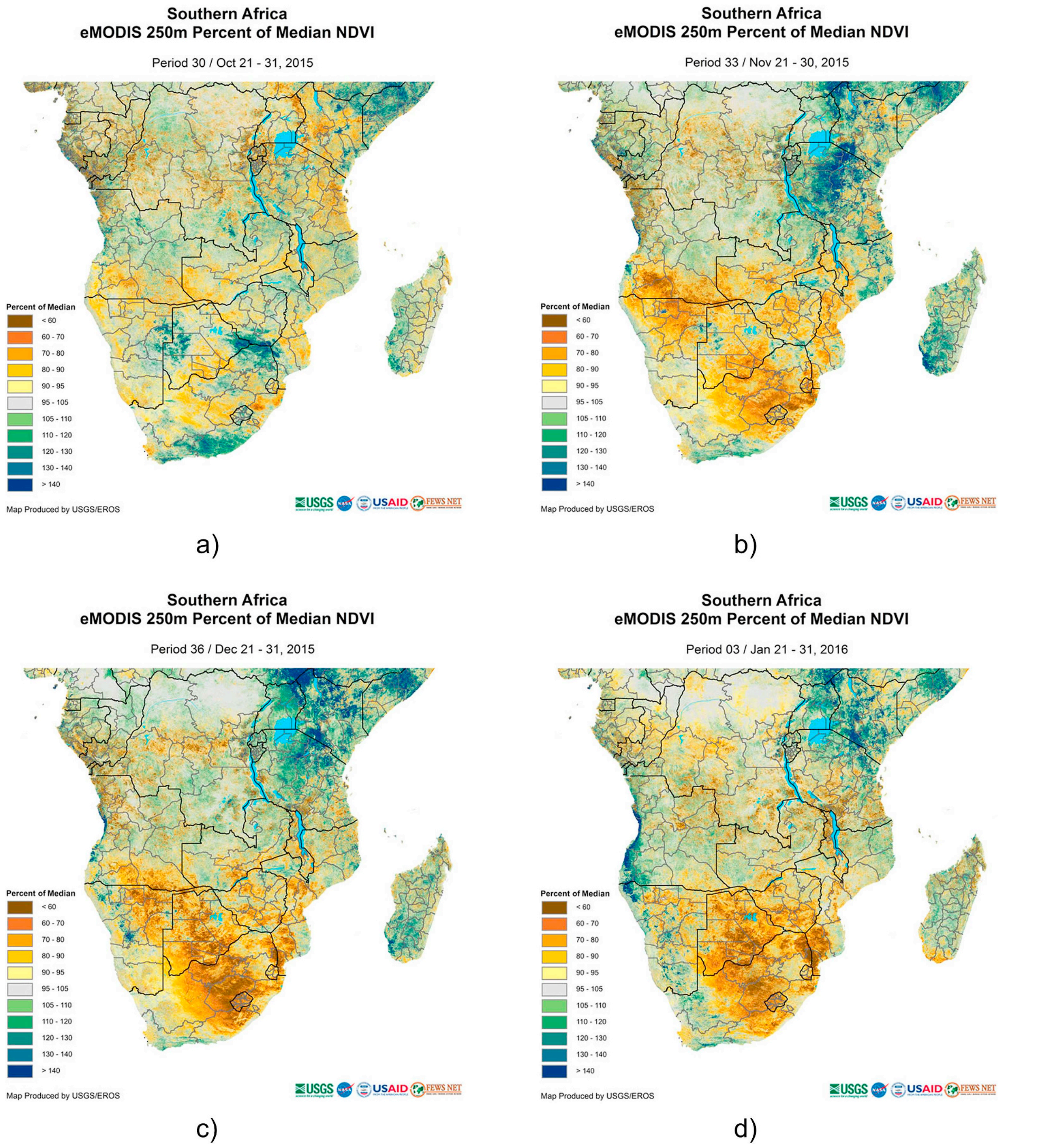


Fig. 4. NDVI expressed as a percent of median for (a) 21–31 October 2015, (b) 21–30 November 2015, (c) 21–31 December 2015 and (d) 21–31 January 2016.

Security" (FAO et al., 2016). This statement included the joint assessment from the CM4EW bulletin, which garnered high international visibility for the CM4EW. The information from the first issue of the CM4EW bulletin published in February 2016 was immediately taken up by various organizations including WFP, USAID, and the South Africa Agricultural Business Chamber (Agbus) members, and used to inform their response to the developing disaster, which ultimately left approximately 40 million people requiring humanitarian assistance at a cost of approximately 2.4 billion USD (SADC RVAA, 2016). South Africa utilized this strategic information for logistical planning as many Southern Africa countries required food aid and grain imports. In anticipation of the significant volumes of grain that would have to pass through the grain handling harbors in South Africa en-route to neighboring countries, the information in the bulletin was of significant value in logistical business planning. This information was used to identify affected countries and the relative magnitude and geographic locations of the anticipated shortages. This in turn facilitated informed business decisions regarding harbors, road and rail transport routes to avoid un-necessary stockpile build up at the harbors (J. Purchase personal communication 22 June 2016). With early warning of drought and disaster as provided by the CM4EW products, disaster relief mechanisms can be triggered at earlier stages of development, allowing for appropriate action to be taken by humanitarian agencies and national governments.

In contrast to the extreme Southern African droughts seen during the 2015/2016 season, the 2017/2018 season was characterized by a

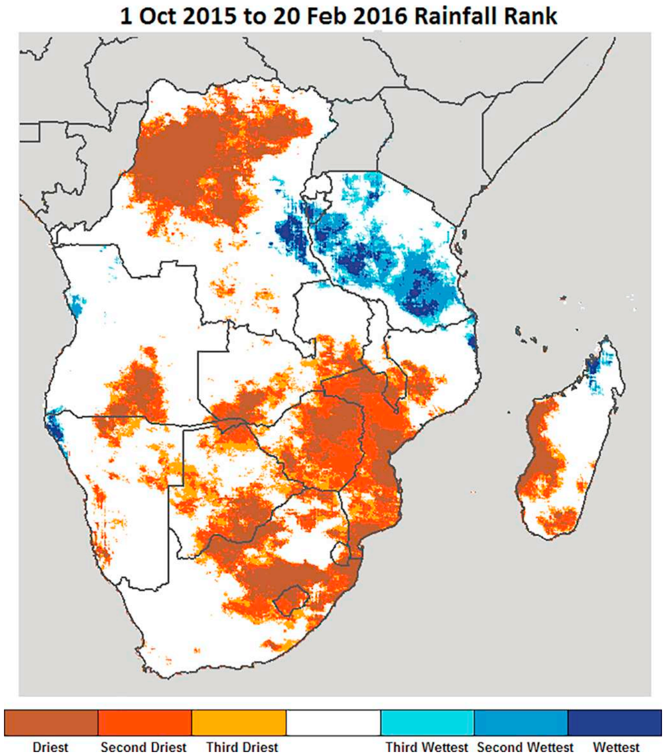


Fig. 5. CHIRPS rainfall ranking for the period 1 October 2015 to 20 February 2016.

milder drought that was more difficult to detect using EO data and analysis alone. As such, the 2017/2018 season provides a good example of the large uncertainty that surrounded the various agency assessments during the season, and the value of sharing not only the EO based assessments but also information from the ground networks and other resources. The 2017/2018 main crop season in Southern Africa started in late 2017 as is usual, however, from late December 2017, the region began experiencing a dry spell with high temperatures lasting 20–30 days or more in many areas. In the first half of February, rainfall picked up again and continued through the end of the season with near-normal rainfall distribution. This led to a quick recovery of green biomass as shown by the NDVI signal for the region. However, plant reproductive systems for early-planted crops had been damaged by the extreme weather conditions during the dry spell, and resulted in unusually low crop yields in several Southern African countries. This situation again led to several discrepancies between the partner assessments over the region.

From the middle of the season in February/March, crop condition analysis based on remote sensing failed to accurately capture the impact of the early season heat and moisture stress. In particular, remote sensing data failed to pick up on the differential impacts caused by delayed planting. Late-planted crops fared considerably better than early-planted crops in many parts of the region. This phenomenon was reported from field observations in parts of Zimbabwe and Zambia and in some cases, late-planted crops recovered in February after the dry spell, while early-planted crops in adjacent fields produced little to no harvest. Monitoring tools such as the Climate Engine (Huntington et al., 2017) or the ASAP High Resolution Viewer (Rembold et al., 2018), which features high-resolution 30 m Landsat and 10 m Sentinel 2 NDVI, also enabled CM4EW analysts to identify this pattern, but the extensive

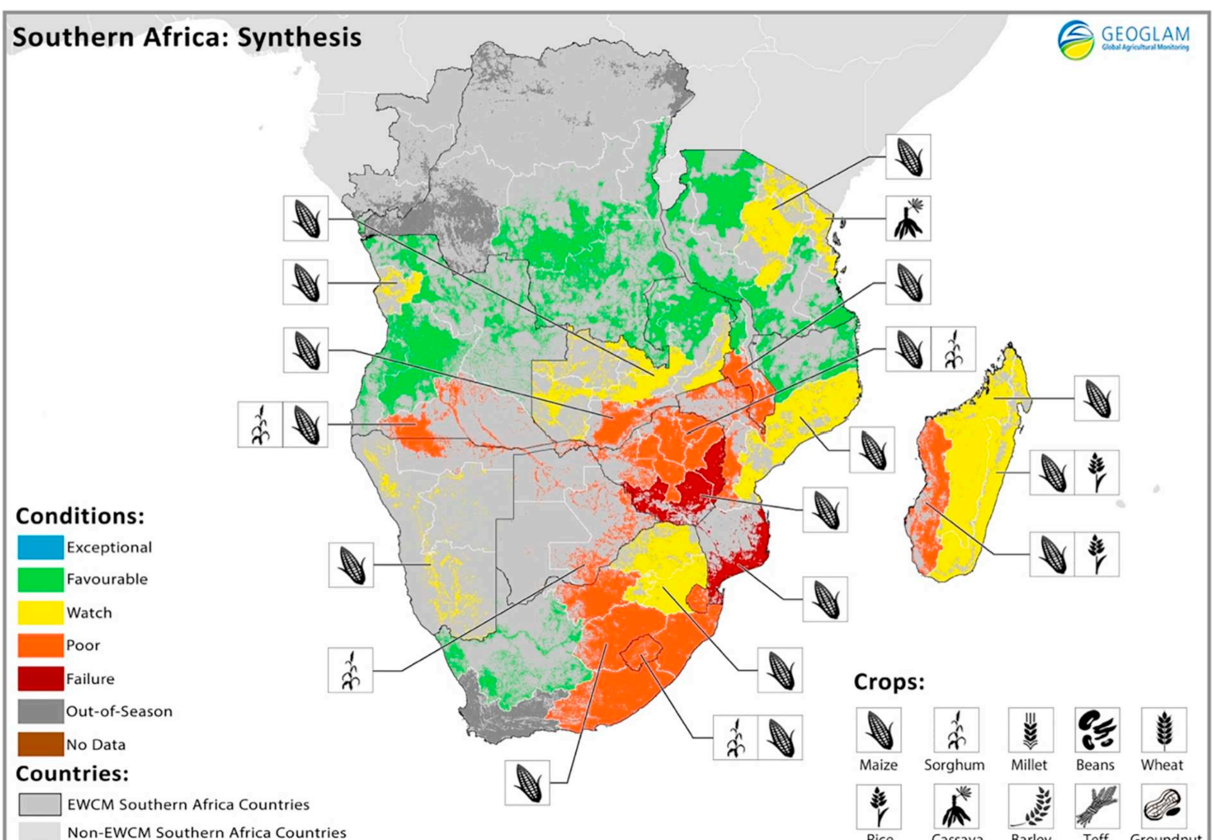


Fig. 6. Southern Africa crop condition map included in the first issue of the CM4EW, February 2016.

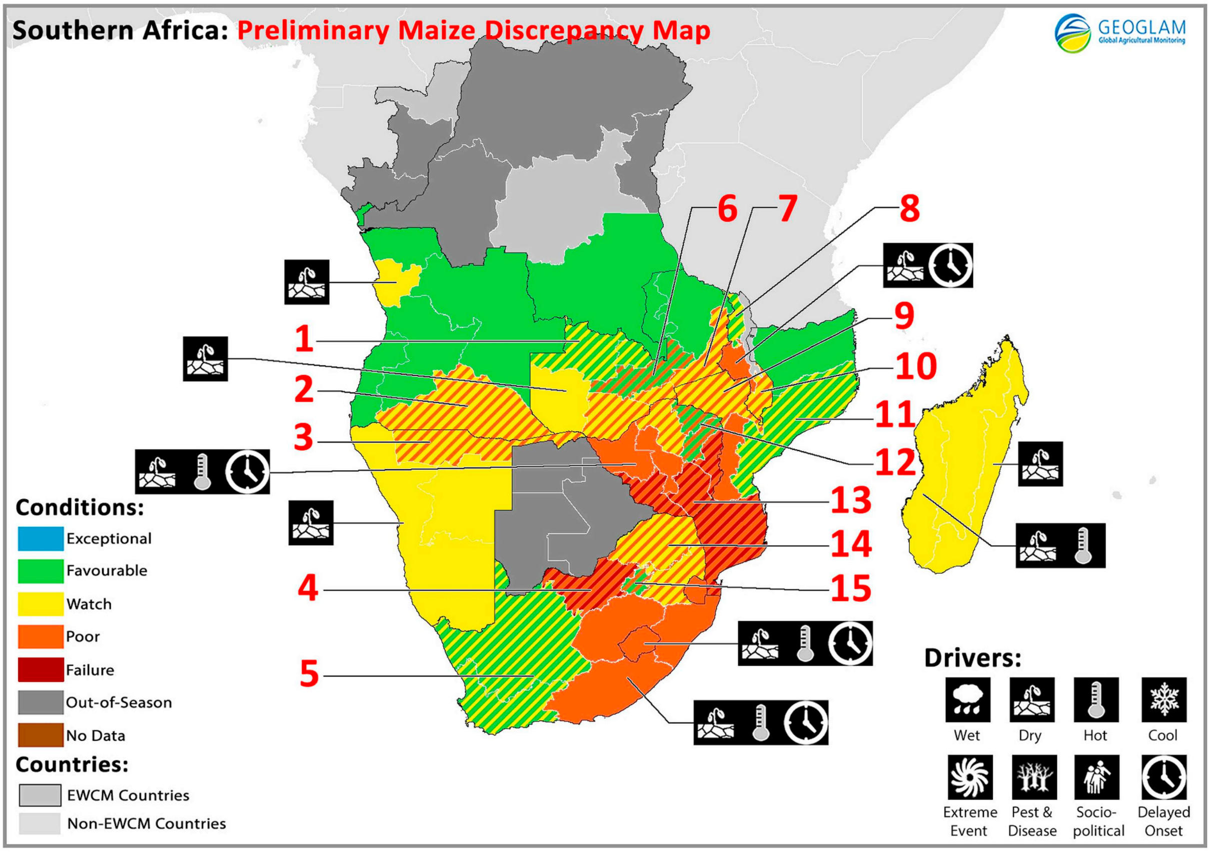


Fig. 7. Southern Africa discrepancy map from first CM4EW assessment, February 2016.

cropped area requiring analysis precluded the possibility of a detailed end-to-end analysis at high resolution. On the other hand, Lesotho also experienced a number of agro climatic hazards that were not easily detected by the common EO-based monitoring tools including unseasonal snowfall, extreme cold temperatures and frost in November 2017, as well as localized hail storms and flash floods in March 2018 (SADC RVAA, 2018).

Given the complexity of the season and its outcomes, the CM4EW crop assessments over the region depended largely on ground reports provided by the regional and national partners (Fig. 8). The partner discussions were extremely useful for all sides to understand and evaluate the information correctly, weight the importance of each source of evidence and to provide timely and reliable information about the national production prospects to their institutions and to the broader monitoring community. While EO play a key role in the CM4EW process, it is critical to integrate these data with other information resources in order to provide a comprehensive view of likely production impacts. This is particularly important in early detection of extreme events such as droughts. In such instances, sharing expertise, ground data, model output and analyses among partner organizations enables the CM4EW to reduce uncertainty and provide an authoritative source of information on crop conditions.

4.2. Afghanistan Case Study: importance of EO data and converging evidence in conflict areas

Central Asia presents challenges for agricultural monitoring due to its unique seasonality and lack of reliable ground information, particularly in Afghanistan, where security concerns limit field-assessments. As a result, crop condition assessments for the area are primarily EO-data driven. The analytical capabilities of CM4EW partners in this domain have played an important role in helping to provide reliable, timely information, as exemplified in the 2017/2018 season.

There are two primary growing seasons in Afghanistan. The first includes a winter wheat and barley season; winter season sowing occurs in October and November, followed by a dormant period and early spring growth, which lends itself to harvest of winter crops in May and June. Winter crops are highly dependent on the availability of water for irrigation, namely from spring snowmelt. The second season, largely spring wheat with some rice and maize, involves sowing in March to June and seasonal growth through August. Second season crops are dependent on spring rains and any additional irrigation water that is still available during the summer dry period. Wheat and maize harvest typically begins in August, with high elevation wheat harvest extending into late September and rice harvest concluding in November.

The 2017/2018 growing season was characterized by below-average snowfall and spatially inconsistent spring rains, which led to significant drought conditions in the north and northwestern portions of the country. In some areas, seasonal snow water volume set new record minimums (Kumar et al., 2012). Fig. 9 shows that in the western basin feeding the Herat area (Hari River), snow water volumes reached record low levels in the latter half of January and parts of early February. The seasonal maximum snow water volume for 2017/18 in this area, which is typically reached in late February/early March, was less than half of the normal peak.

Assessments submitted by the CM4EW partners in late January 2018 expressed concern about the lack of seasonal precipitation and snow accumulation and concerns continued to heighten as the region transitioned into the spring rainy season. During the month of March, warming temperatures depleted snow water volumes, diminishing the opportunity for crops to recover from the effects of poor seasonal snow fall. As of early March, the seasonal percent of normal rainfall based on CHIRPS data showed deficits on the order of less than 70% of average throughout the north, west, and southwest portions of the country

(Fig. 10). The only areas with winter season precipitation near or above normal were limited to small pockets in central and west Afghanistan, as well as a fairly extensive portion of eastern and southeastern Afghanistan. Despite a good start to the spring rains in March, as the rainy season progressed through April and into May, many of the same areas in the north and southwest of Afghanistan showed significant rainfall deficits.

The primary vegetative growth phase for both irrigated winter crops and rain-fed spring crops takes place between March and April. At this stage in the growing season, the quality of the vegetation conditions can be assessed with a variety of remote sensing-based products including NDVI (Brown et al., 2015) and actual evapotranspiration (ETa) (Senay et al., 2013), which provides a measure of the combined evaporation from the soil and transpiration from vegetation. By looking at both time-series and anomalies, the CM4EW assessments were able to identify areas impacted by poor moisture conditions and provide alerts as to where declines in agricultural yield were likely to occur. For example, EO data revealed that first season irrigated crops in the southwest and western portions of the country, which had been seasonally dry, received adequate irrigation water from spring snowmelt for near-normal crop development. In contrast, the dry areas in the north and northwest-particularly the provinces of Badghis, Faryab, and Jawzjan-showed very poor conditions for winter crops. The largest NDVI anomalies were most evident in the northern portions of the country, with some poor conditions in the far west and south central regions (Fig. 11). The northern provinces account for approximately 40% of the total wheat production in Afghanistan and represent the primary rain-fed cropping areas. The same spatial patterns seen in Fig. 11 were evident in cumulative ETa anomalies between March and the end of May, in which deficits showed less than 50% of median (2003–2015) ETa and served as corroborating evidence for the CM4EW assessments.

This case study demonstrates that remotely sensed EO are invaluable for assessing conditions in areas where repeated field assessments are prohibited. Partners' assessments, which were validated, harmonized and shared through the CM4EW process, provided insights into potential impacts of reduced water availability on crop production in Afghanistan and other parts of Central Asia at a very early stage in the season. As the moisture deficits became more evident and the drought conditions began to emerge, the reporting on crop conditions effectively mirrored this reality in the monthly bulletins. Unfortunately, the suspected deficits were confirmed by a pre-harvest field assessment that reported significant rain-fed crop loss in northern Afghanistan and aggregate reductions in overall wheat production for the country. The information provided by the CM4EW as the season developed was routinely used by the partner organizations to track the situation in Afghanistan and inform their responses, and was included in briefings to the Afghanistan Ministry of Agriculture, Early Warning Information Working Group, and to the USAID Mission. In addition, this information fed into the FEWS NET seasonal forecast review and scenario development process which assesses food security needs several months in advance throughout the growing season using the Integrated Food Security Phase Classification (IPC) scale. The end-of-season CM4EW report (Fig. 12) showed good correspondence between crop monitor classifications in the north and northwest of Afghanistan (poor with areas of failure) and IPC outlooks for the October 2018–January 2019 period, which included IPC phase 4 (emergency) in parts of Badghis and Faryab provinces, with IPC phase 3 (crisis) throughout most of northern Afghanistan (FEWS NET, 2018). This information was incorporated into FEWS NET Food Security Outlook Briefings for USAID decision makers. It also helped FEWS NET and partners demonstrate the atypically high food security needs in Afghanistan following the 2017/18 drought. Resources were mobilized accordingly by USAID and the international community to respond to the high level of need during the January–April 2019 lean season.

5. Discussion: the CM4EW impact and applications

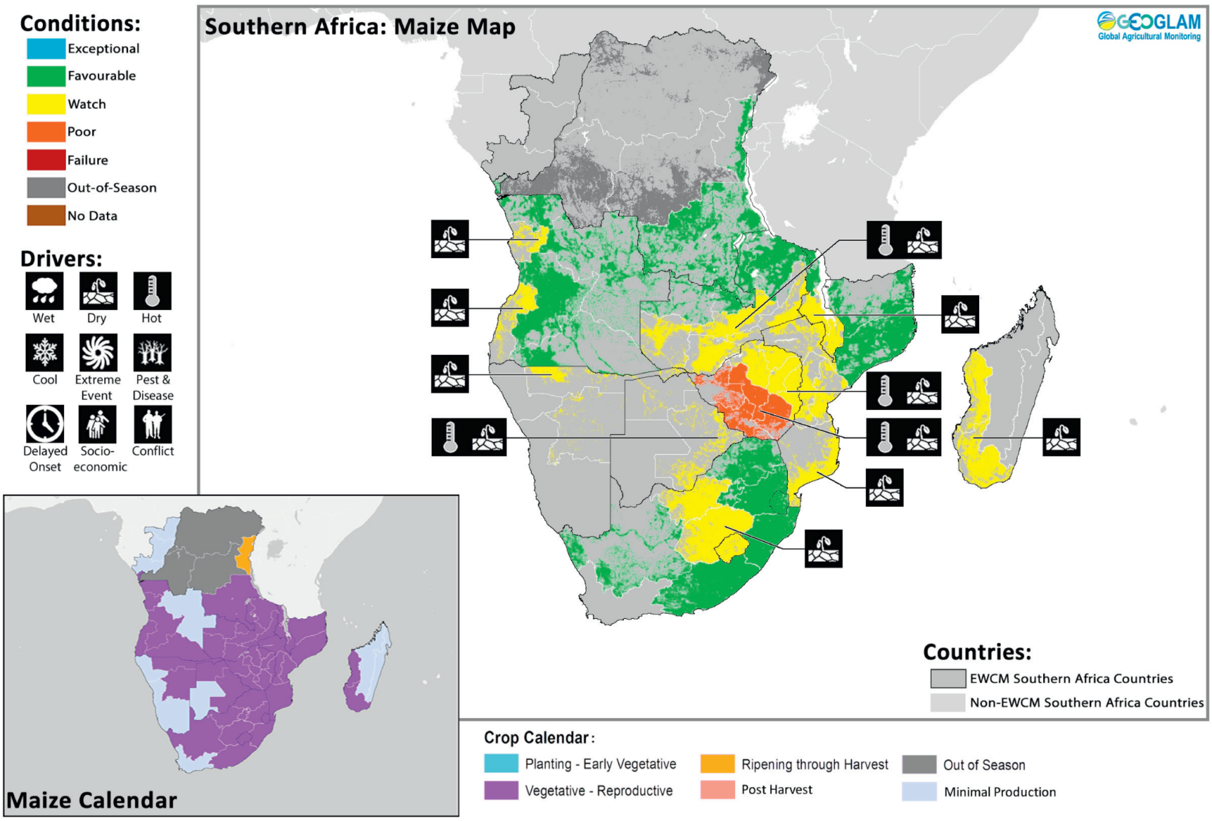
The CM4EW initiative is driven by the demand for improved and reliable information on crop conditions over early warning countries, with the goal of empowering evidence-based food security policy and decision-making. This demand is reflected in public support, media references, and in the actions of government and UN organizations which have adapted CM4EW products for use in decision making on food allocation and humanitarian assistance (England and Terazono, 2016; Omondi, 2017; UN News, 2017; Patel, 2018 and Southern Africa as detailed in Section 4.1). Most recently, in February 2018, the United Nations Office of Humanitarian Affairs (UNOCHA) published a special alert for Southern Africa detailing the emerging drought and pest conditions following significantly below-average rainfall early in the season, which affected main season crops. This report outlined the importance of assessments such as those provided by the CM4EW bulletins, and emphasized the need for increased frequency and detail in monitoring efforts, which can be used in turn to inform appropriate actions and vulnerability assessments for early warning and early action, on a more frequent basis (UNOCHA Food and Nutrition Security Working Group Southern Africa, 2018).

The organizations that contribute to the CM4EW are also key users of the information provided, each benefiting from dialogues with partner organizations in the consensus process, to reinforce internal analysis. It is important however to note that the users within the partner organizations generally fall under policy and decision-making units, whereas the contributors are generally within the technical units of these organizations. The interactive process of the CM4EW facilitates a verification exercise to better understand prevailing crop conditions and to refine crop production forecasts (e.g. at UN FAO).

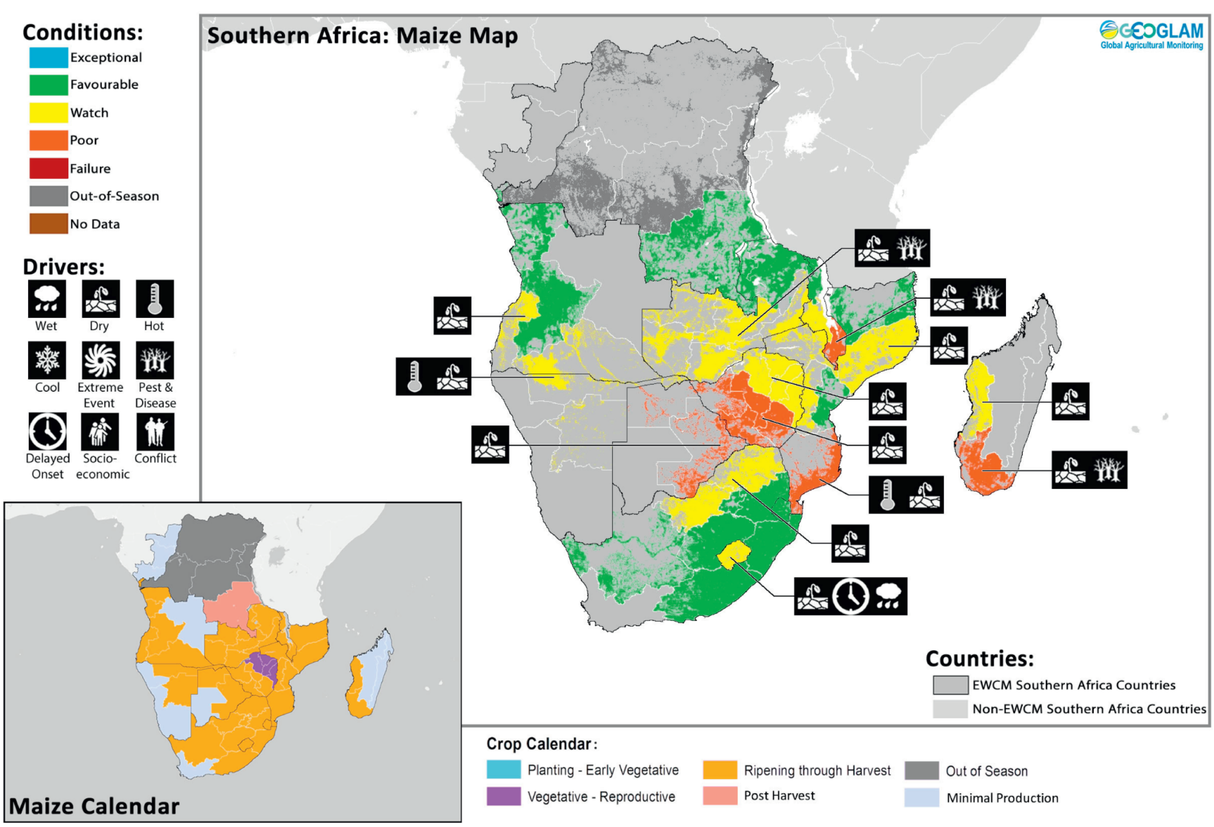
Within the EC, the CM4EW bulletin has proved a useful informational product to provide to different EC services, including those in charge of rural development, food security and humanitarian assistance. Because the monthly CM4EW bulletin does not contain direct policy recommendations, the main documented use of the CM4EW bulletins within the EC is to inform other policy documents such as the 2016 Report on Food Crises (Nkunzimana et al., 2016). The EC JRC also recommends the use of the CM4EW during national level or regional consolidation IPC that form the basis for the annual Global Report on Food Crises. The CM4EW is relevant especially in IPC analyses wherein country information about food production is scarce or unreliable. The CM4EW products are also used by FAO regional offices to support multi-organizational humanitarian programs, and support a consensus-based decision-making process. Likewise, for UN WFP the contribution to the CM4EW by its analytical teams goes hand in hand with its usage by the organization's regional bureaus and country offices. The value of the CM4EW outputs lies in its consensual dimension and the weight this carries particularly for its partners. The evidence it provides is also important for the organization's advocacy efforts.

FEWS NET food security analysts update their scenarios of food insecurity on a monthly basis with the purpose of providing timely, accurate, and transparent outlooks for food insecurity in the developing world. The CM4EW bulletin is one of the many data and information products that the FEWS NET analysts use as inputs for scenario development.

The immediate audience for the CM4EW food security assessments is within the USAID Office of Food for Peace, though they are used by many partner organizations around the world as well. Formal briefings to Food for Peace are made monthly to help guide decisions for allocation of resources for food assistance. Maps and charts from the CM4EW frequently appear in these briefings, to help communicate the agricultural situation. Seasonal progress and end of season maps for maize in Southern Africa appeared regularly in 2016 due to El Nino impacts, and the practice has persisted in that region throughout 2017

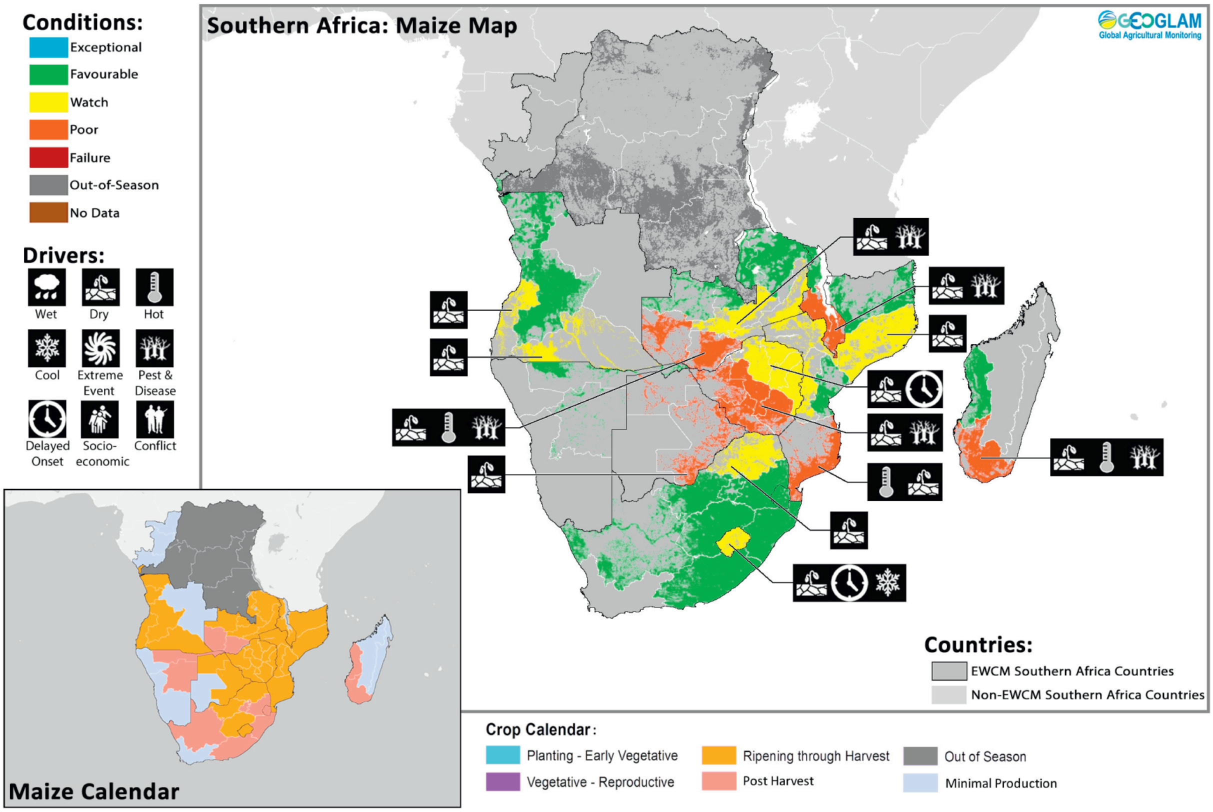


a)



b)

Fig. 8. 2018 seasonal progression of crop condition as reported in CM4EW Southern Africa crop condition maps from January (a), March (b), and May (c) bulletins and the final post-harvest crop condition map from the July (d) bulletin, showing final consensus conditions for the season.



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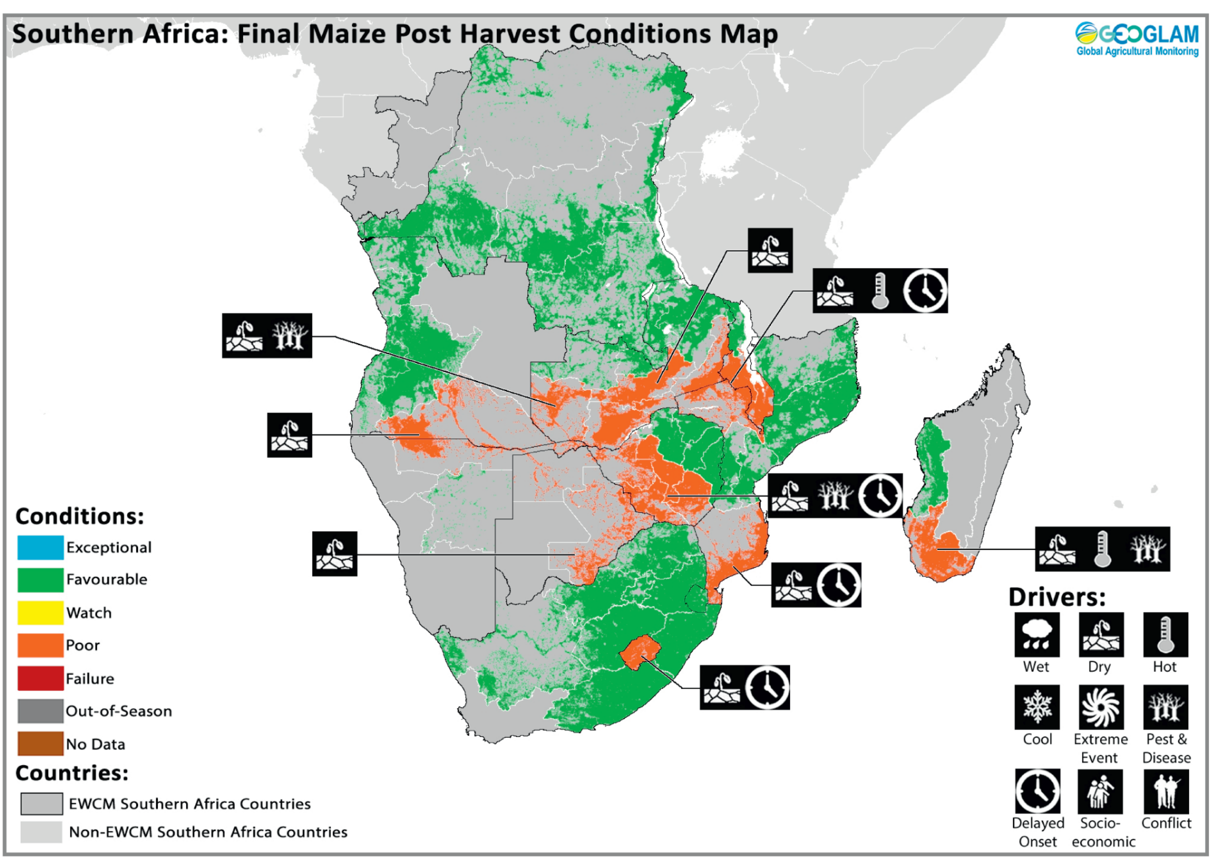

d)

Fig. 8. (*continued*)

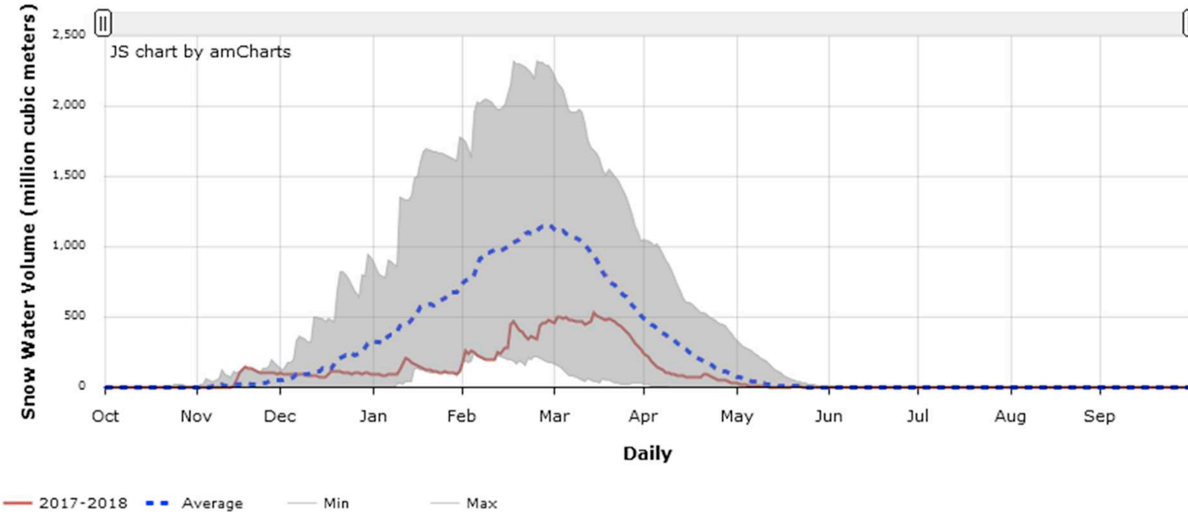

Fig. 9. Snow water volume time series for the basin feeding the Hari River in western Afghanistan. Gray shaded areas delimit the historical minimum/maximum, the dotted blue line represents the average (2001/02–present), and the brown line tracks the 2017/18 season (NASA GSFC/USGS EROS). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

and 2018, even after the crisis subsided. Other notable appearances of the CM4EW in FEWS NET food security outlook briefings include depiction of East Africa drought impacts in 2017, generally favourable outcomes in West Africa in 2016 and 2018, and poor spring wheat outcomes in Afghanistan in 2018. The credibility of the CM4EW's consensus crop condition classifications has made it a routinely referenced source for FEWS NET.

The information covering the CM4EW reporting in Southeast Asia is utilized by the ASEAN (Association of Southeast Asian Nations) Plus Three Emergency Rice Reserve (APTERR), a regional entity responsible for monitoring and advising on the balance of rice demand and supply in Southeast Asia. The information provided by the CM4EW is used to validate APTERR information on rice crop growth and production impacts caused by anomalies of climate and weather. In addition, the CM4EW products are provided to executive officers in ministries of agriculture in the ASEAN region and used to support short-term rice crop yield forecasting and the application of agro-met information to yield models within the ministry forecast departments. At the national scale, the CM4EW assessments are used to verify local government reporting on rice crop planting and cultivation.

The main goal of the agriculture department at the Intergovernmental Authority on Drought and Development (IGAD) Climate Prediction and Application Centre in East Africa (ICPAC) is to collaborate with relevant agricultural institutions to provide climate and related information in the agriculture, livestock and food security for early warning. To this end, the CM4EW has provided the tools for IGAD/ICPAC to provide information for the 11 East African member countries. The CM4EW was selected by ICPAC as a tool to support the collection and dissemination of early warning information under the Global Monitoring for Environment and Security in Africa (GMES &

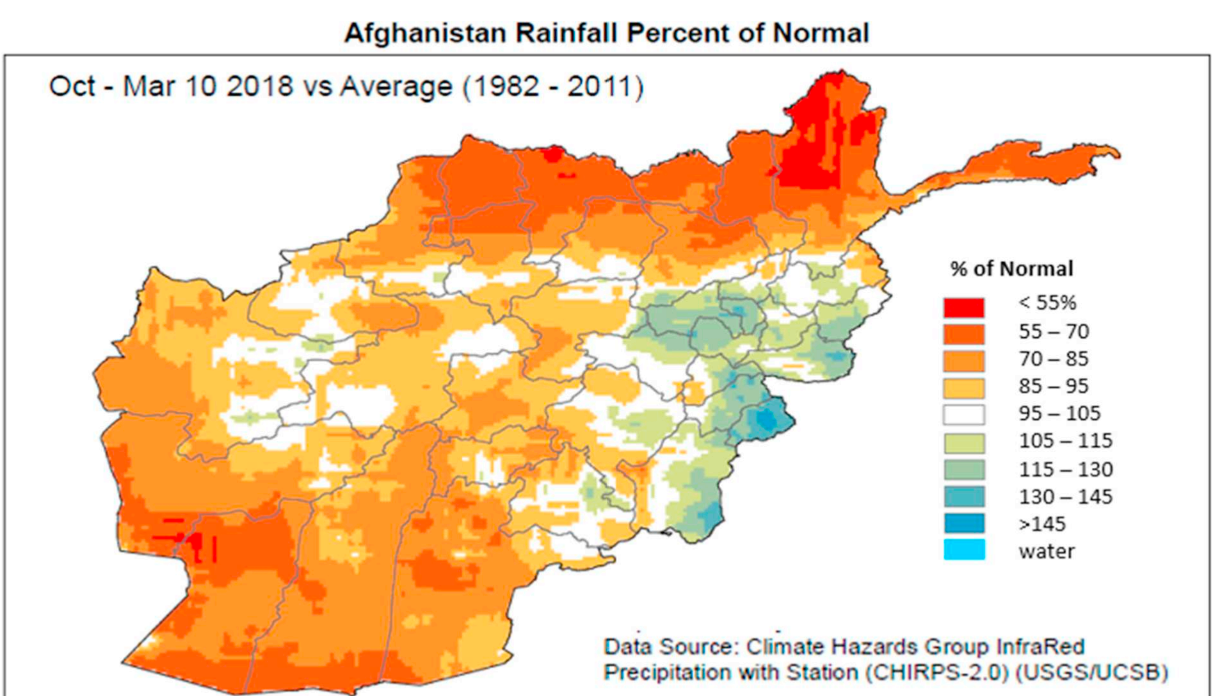

Fig. 10. Percent of normal rainfall from October through March 10, 2018. Climate Hazards Group InfraRed Precipitation dataset (Funk et al., 2015).

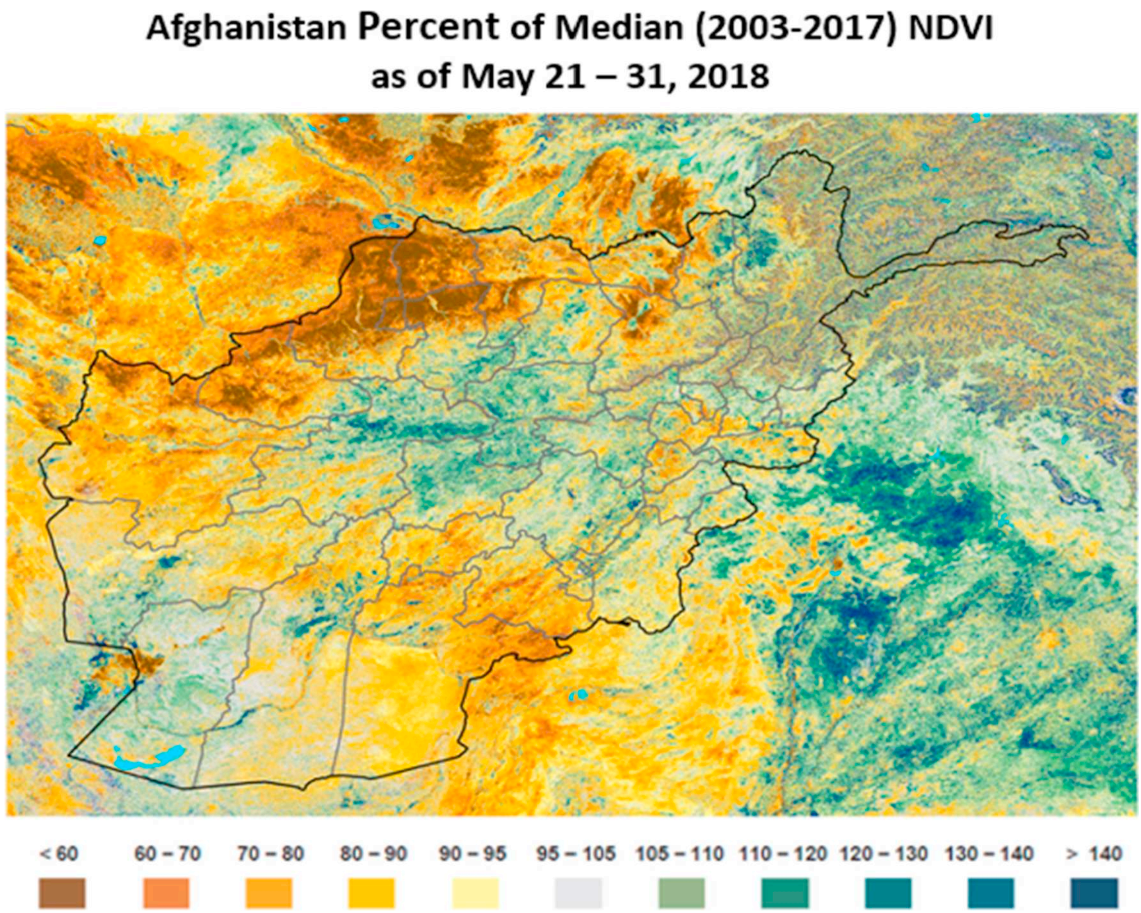

Fig. 11. NDVI percent of median (2003–2017) towards the end of the spring rainy season, illustrating the severity of vegetation conditions as of the end of May. The dark brown areas that dominate the northern provinces of Badghis, Faryab, Jawzjan, Balkh, and northern Sari Pul represent vegetation that is less than 60% of normal greenness. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

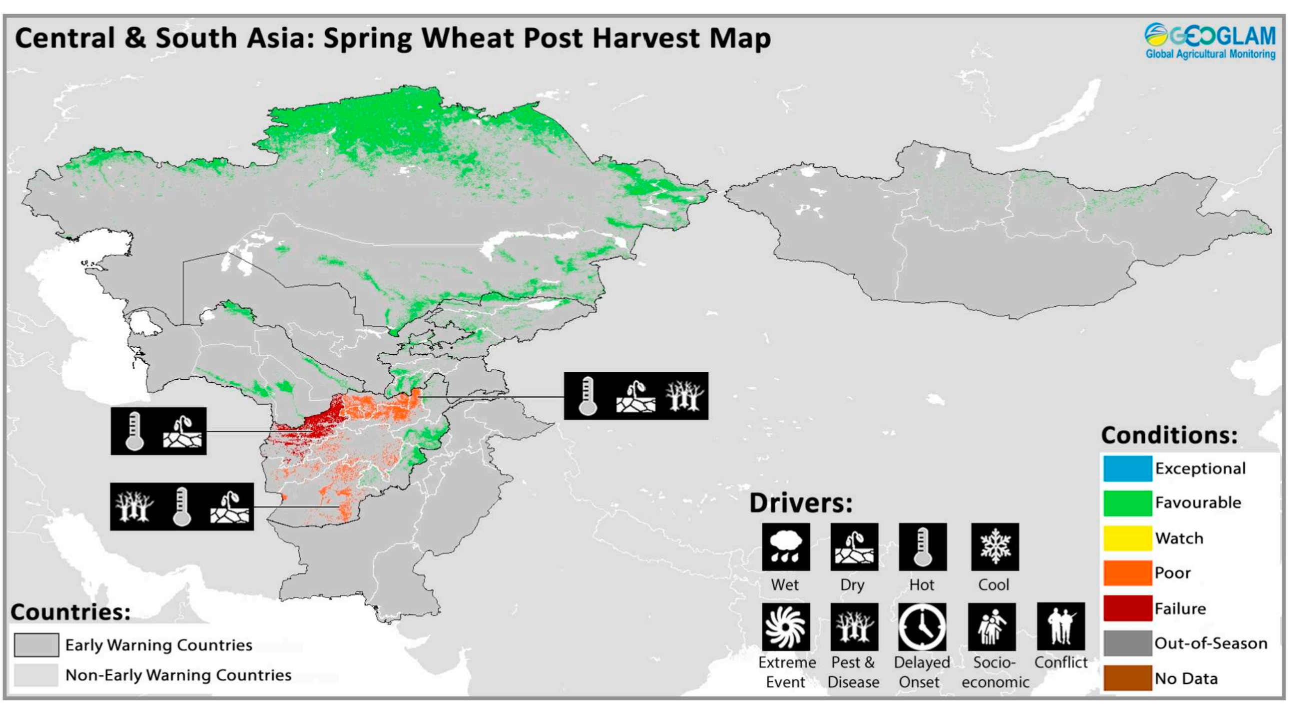

Fig. 12. The CM4EW Central and South Asia Post-harvest map for spring wheat, October 2018.

Africa) project (https://au.int/GMESAfrica). So far, the application has seen the use of the regional Eastern Africa Crop Monitor (EACM) in Food Security and Nutrition Working Group (FSNWG) monthly assessments and Tegemeo institute of Agricultural Policy and Development in food situation assessment. In addition, through ICPAC's partnership with the Eastern Africa Grain Council (EAGC), the CM4EW and EACM crop conditions have become valuable information sources for EAGC assessments and generation of advisories to farmers and other users. An example of this is found in the Regional Agriculture Trade Intelligence Network (RATIN) Bulletin developed by EAGC. Through strategic collaborations, this has fostered user-driven service for IGAD/ICPAC.

The individuals and organizations who contribute to the CM4EW each month benefit from the dialogues and interaction with counterparts at partner organizations during the consensus-building process, and from reinforcing internal analyses. The interactive aspects of the CM4EW process facilitate a verification exercise designed to help better understand prevailing crop conditions and to refine crop production forecasts. The collaborative process and community created through CM4EW supports trust and mutual respect among partners and serves to strengthen the discourse surrounding crop production and regional food security and the dissemination of actionable information to decision makers.

5.1. Adapting a global process to meet regional and national needs

Following the successful implementation of the CM4EW, the first National Crop Monitor was developed with the Tanzania Ministry of Agriculture (MoA) National Food Security Division, the agency responsible for monitoring and reporting on the status of food security in the country. After a needs assessment, the MoA was keen on reestablishing their national food security bulletin and were cautious to ensure the components in the bulletin could be sustained given the limitations of the previous bulletin. Appreciating the capabilities of the Crop Monitor system in helping to synthesize all the information available into actionable information, several capacity development trainings were held with MoA supported by Agri-Sense STARS Project (http://agrisense.org/). The team trained on the use of remote sensing information from the Global Agriculture Monitoring System (GLAM-East Africa) (Becker-Reshef et al., 2019) that complimented the ministry's existing data collection systems. Since November 2015, the MoA has been compiling and reporting information in the Tanzania Crop Monitoring and publishes NFSB through an email list.

Similarly, through a partnership with the Office of the Prime Minister Department of Relief, Disaster Preparedness and Management (DRDPM), the Uganda Crop Monitor was established to be the primary tool for synthesizing crop and pasture conditions information as part of the Uganda-National Integrated Early Warning Systems (U-NIEWS) Bulletin. The National Emergency Coordination and Operations Center (NECOC) has been analyzing and publishing early warning information on a monthly basis since November 2016.

With increased success and requests for national monitors and the existence of The Greater Horn of Africa Climate Outlook Forum (GHACOF), a regional Crop Monitor was proposed during GHACOF45 intended to synthesize national level information from National monitors in existence and from other IGAD Climate Prediction and Application Centre (ICPAC) countries. The proposal was well received and national analysts were trained at ICPAC to manage and coordinate reports. The Eastern Africa Crop Monitor Bulletin was launched in May 2018 during GHACOF49. As the first regionally run monitor, a main feature was to ensure coordination of assessment from national monitors and linking these to the global CM4EW Bulletin. The Eastern Africa Crop Monitor report also contextualizes climate outlook information, a primary product from GHACOFs, and provides a season outlook as part of the forums' reports.

The CM4EW process has proven to be not only adaptable, but also scalable, replicable and sustainable. Working with national ministries, the system and process has now been adapted in a number of countries including Tanzania, Uganda and Kenya as well as at the regional scale (within ICPAC) in Eastern Africa. The process has been integrated within these agencies that operate differently but with the same standardized approach, and comparable reports that combine remote sensing and traditionally collected information sources, enhancing the capacity of national analyst to use EO data regularly. These activities, undertaken through development and partnership with the GEOGLAM Crop Monitor, work to address SDG target 3.D, and 12.A, in supporting national and regional capacity in East Africa for early warning and risk reduction (United Nations, 2015a).

5.2. The CM4EW and the UN SDGs

Although the CM4EW was established under GEOGLAM via the 2011 G20 Action Plan on Food Price Volatility and Markets, it has broad applicability to both help to attain the 2030 Agenda for Sustainable Development (via the Sustainable Development Goals and their targets), as well as to help monitor progress towards the Goals and targets, as laid out in the Global Indicator Framework (IAEG-SDGs, 2018a).

Specifically, the CM4EW contributes towards Goal 2 through support for target 2.1, as well as Goal 1 target 1.5, Goal 3 target 3.D, and Goal 13 target 13.3 (as summarized in Section 1.2) by providing timely updates on crop growth status that in turn provide early warning of emerging food production challenges and inform early action and mitigation. There are considerable opportunities for improving the science which underpins quantitative crop assessments, in particular in the smallholder systems which characterize the least developed countries (AMIS Market Monitor, November 2018). In this vein, the CM4EW has a new partnership with the University of California Santa Barbara (UCSB) Climate Hazards Center (CHC) to integrate short-term and seasonal forecasts into the CM4EW Bulletins, in order to situate the crop conditions in broader scale climatic and weather variations. In addition, while the CM4EW is a monthly product that addresses conditions within the current growing season, there is potential to track the nature, extent, and severity of crop growth issues within season and across multiple seasons (Challinor et al., 2014; Oteros et al., 2015; Ray et al., 2015; Zhang and Zhang, 2016), providing a key instrument to inform adaptation to and mitigation of climate change related shifts in food production, further contributing to Goal 13 target 13.3.

Finally, the CM4EW contributes to the structures and national capacity that will be critical to the SDGs' success. For example, in the case of Goal 12: Sustainable Consumption & Production, target 12.A "Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production", the CM4EW, and in particular its use by and deployment in national contexts via capacity development and technology transfer, directly underpins this goal. Similarly, for Goal 17: Global Partnerships, several of its targets focus on capacity development, South-South, North-South, and triangular regional and international cooperation, and improved provision of high-quality, timely, and reliable data disaggregated by geographic location (targets 17.6, 17.9, and 17.18). The CM4EW is a uniquely international initiative in its ability to bring together the international community through cooperation to generate spatially explicit, geographically disaggregated information on crop conditions. There is much to be learned from the GEOGLAM Crop Monitors with respect to communication, participation, collaboration, and delivery of actionable results at national and global levels, as well as with respect to the value of Earth observations, that merits deeper consideration by the UN Custodian Agencies and the IAEG-SDGs. To advance at the rate necessary to fulfill these policy frameworks and more importantly to meet these global challenges, the communities involved will be well-served by capitalizing on resources made available through these distinct mandates (G20 Action Plan and 2030 Global Agenda), and by leveraging existing, user-adopted data streams and efforts, such as those characterizing the CM4EW.

6. Conclusions and way forward

The GEOGLAM Crop Monitor for Early Warning provides a public good of timely, EO-driven and actionable information on crop conditions within the countries most vulnerable to food insecurity and provides a novel and impactful use of EO for informing food security decisions. The CM4EW takes a novel approach to increasing confidence of crop assessments by bringing together on a monthly basis the international community with a mandate for agricultural monitoring in these parts of the world. These joint consensus-driven assessments are based on each agency's monitoring system that rely on a range of EO indicators and products, agrometeorological models, ground information, the analyst's expertise and joint discussions. The Crop Monitor initiative has established a mechanism for discussion, and airing of discrepancies across agency assessments, leading ultimately to internationally endorsed information that is routinely used by a range of organizations to inform food security decisions.

Timely and transparent information on crop conditions and production prospects, at the field to global scales, can contribute to achieving the goal of Zero Hunger, as exemplified by the IAEG-SDG indicators, which do currently utilize EO as well as interactions between the Group on Earth Observations and the UN Custodian Agencies (Anderson et al., 2017; IAEG-SDGs, 2018b; Ryan, 2017). Such information has a key role to play in providing early warning of food shortages and guiding humanitarian responses, ensuring market transparency and stability, and informing national agricultural policies. The underpinning value of the CM4EW is that by sharing assessments, data, expertise, and ground information on a regular basis, we can significantly reduce uncertainty around production prospects, and encourage coordination among the primary humanitarian organizations and national governments. The open process is continuing to help bridge the gap between the remote sensing and policy communities, while increasing communication, trust, collaborations and knowledge transfer among international, regional and national organizations involved in food security. Ultimately, the CM4EW provides a public good of transparent and consensus-driven crop condition information to improved response planning and thereby contributing to improved food security.

The information sharing that results from the CM4EW consensus assessments also serves to reduce duplication of methods and systems, thereby conserving resources across agencies and increasing the efficiency of EO and field data collection. This is directly in line with a key lesson learned through the Millennium Development Goals and stated clearly by the UN in preparation for the SDGs: “once the geospatial data are created, they can be used many times to support a multiplicity of applications” (United Nations, 2015b).

Whether by humanitarian organizations, governments or farmers, key decisions are routinely being made, that could benefit from more timely and accurate information on crop conditions and prospects. While major advances have been made particularly for monitoring large scale agriculture, across major grain producing countries, current capabilities for effective monitoring of small-holder systems that characterize much of the world's most vulnerable countries are still a long way off and there remains an urgent need to advance in this domain. On the data side, one of the main impediments for improving crop condition and production assessments is access to reliable, representative ground data. While we are in the era of ‘Big Data’, we are actually rather data-poor in terms of ground observations, which are critical for developing and assessing the accuracy of RS based indicators and methods. Amending this data deficiency is a main priority for the early warning community and the agricultural monitoring community at large. Moving forward, it will be important to foster innovative methods for utilizing the increasingly available high resolution data, new public-private partnerships, and advanced crowdsourcing approaches that will enable access to and collection of such data and take full advantage of the advances in data analytics methods for improving current models and methods.

Going forward, the CM4EW will continue to strengthen regional and national partnerships and participation, and to support enhanced capacity for national assessments as well as coordination with the various national and regional crop monitors. Emphasis will also be given to developing improved baseline information on crop calendars and cropping systems distribution. In addition, new layers will be developed to distinguish between marginal and high production areas within the countries we are monitoring. Given the importance of weather forecasts for predicting crop outcomes, we will also work closely with new partners including the UCSB CHC to integrate short-term and seasonal forecasts into the CM4EW assessments. This will further enhance the CM4EW capabilities as well as work towards achieving SDG's as they intersect with early warning, increasing resilience, and reducing vulnerability (i.e. targets 1.5, 3.D, and 13.3). Recognizing that rangelands are a critical piece of food security, the CM4EW will partner with the GEOGLAM RAPP (Rangeland and Pasture Productivity) community to develop a rangelands monitoring component. Finally, in response to recent calls from UNOCHA and others, for more precise and frequent information during developing potential food shortages, a new rapid response process and triggering mechanism is currently being developed that would provide rapid, consensus assessment over areas of concern.

Despite the many challenges for agricultural monitoring in support of early warning, significant progress has been made, both from the technical and applications perspectives. Furthermore, the recent revolution in cost and availability of moderate and high resolution data, the commitment from space agencies to offer coordination and long-term observations, and the advances in big data analytics, high-performance computing, and citizen science are all game-changing opportunities for agricultural monitoring capabilities, particularly for small holder dominated countries.

When integrated with complimentary ground and socio-economic data, satellite-based EO provide a key contribution to effective monitoring of our agricultural lands. This in turn is a critical component in the fight for global food security and a shared global challenge that can only be addressed through international collaboration across countries, organizations and sectors, and through innovation in science, technology and more open sharing of data, methods and expertise. It is critical for the user communities, whether ministries of agriculture or humanitarian organizations, to drive the operational research and development. The CM4EW is a good example as it was developed as a direct response to humanitarian organization requests, and supports both national and global goals for sustainable development and human livelihood maintenance. Development of an international consensus bulletin has provided insight into the participating monitoring systems' varied approaches, definitions, and objectives. This opens an important dialogue towards standardization of approaches and improved crop condition information for the broader policy communities. This effort's relevance at national, regional, and global levels, including its intersection with global policy frameworks like the G20 Action Plan on Food Price Volatility and Agriculture and the 2030 Agenda for Sustainable Development, highlights the value of Earth observation for timely, accurate, and actionable decision support and what we can accomplish together as a community in confronting pressing global challenges.

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