

# Integrating Earth Observations into the Formulation and Implementation of National Adaptation Plans: Agriculture and Food Security

GEO Supplement to the UNFCCC NAP Technical Guidelines



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# Foreword

Adaptation to climate change is crucial, particularly for the Least Developed Countries (LDCs) and Small Island Developing States. According to the recent 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) Working Group II contribution (AR6 WGII), the world will face severe climate risks before the end of this century even under low emission scenarios, thereby necessitating ambitious, accelerated action to adapt to climate change.

Established in 2001 under the United Nations Framework Convention on Climate Change (UNFCCC), the Least Developed Countries Expert Group (LEG) provides technical guidance and support to the LDCs in implementing the Convention and the Paris Agreement. The LEG support to the LDCs on adaptation has evolved from one-off planning for urgent and immediate adaptation needs such as in the context of the national adaptation programs of action, to a systematic approach, where activities are iterative, continuous and long-term through the national adaptation plans (NAPs). The process to formulate and implement NAPs creates a comprehensive system through which countries scale up their actions to reduce vulnerability to climate change and integrate climate change adaptation in development planning on an ongoing basis.

Following request by the Conference of the Parties (COP), the LEG in 2012 developed technical guidelines for the formulation and implementation of NAPs framed around the four main elements of laying the groundwork and addressing gaps; preparatory elements; implementation strategies; and reporting, monitoring and review. The guidelines provide the foundation for adaptation actions and support for adaptation. They offer a range of options for dealing with each of the aforementioned elements to

facilitate country-owned and country-driven action, that seeks to harness and build upon national-level capacity.

The supplementary materials to the technical guidelines offer additional in-depth coverage of selected steps and topics, thereby helping enhance the depth and scope of adaptation actions. We are grateful to the commitment of the various organizations in developing these important materials. We are positive that this supplement by GEO will help complement the NAP guidelines by providing guidance on technical and institutional resources required to facilitate access to accurate and long-term information needed for the successful implementation of NAPs. The focus on agriculture and crop monitors is particularly timely given the importance of food systems in NAPs, and the potential that this offers in meeting the Secretary General's call for access to early warning systems by all by 2025. The technical details in this supplement will be useful to the countries as they envision implementation of their NAPs including through relevant programs under the Green Climate Fund, and other channels, related to food systems and climate information and early warning systems.

This supplement and more resources for the formulation and implementation are made available on NAP Central at <https://napcentral.org>.



**Kenel Delusca**  
Chair of the LEG

Smallholder farmers are the backbone of food security in low- and middle-income countries, and they are also most exposed to the impacts of climate change and other environmental and economic shocks.

Science can support them. Advances in Earth observation technology mean that we have an unprecedented array of data and tools to help farmers and their governments monitor trends and respond to threats. Translating this science into better decisions and policies is not an automatic process. People need the right information, at the right time and in the right format.

The Group on Earth Observations (GEO) is determined to bridge this gap in environmental intelligence. I am therefore excited to present the first GEO Supplement to the UNFCCC NAP Technical Guidelines. Spearheaded by our Global Agricultural Monitoring (GEOGLAM) initiative, the supplement provides practical knowledge and skills on how to use Earth observation to enhance the design and implementation of NAPs.

Prepared in advance of COP27, the supplement draws on GEOGLAM's extensive experience in collaborating with governments to co-create solutions to food security challenges — protecting livelihoods and reducing costs for governments.

To implement these guidelines, we continue to support countries' climate adaptation agendas on the ground by co-developing monitoring systems for early warning and early action, based on Earth observations, innovative technology, and public-private partnerships.

Following this first guidance document focused on agriculture, we are committed to expanding GEO's technical support to other critical components of NAPs, such as coastal zones and water resources management.



**Yana Gevorgyan**  
GEO Secretariat Director

## Document Structure

**Part I: Introduction** – This section contains a general introduction to the supplementary guidelines, outlining the importance of Earth observations (EO) for climate change adaptation planning and implementation, how they relate to essential climate variables important for adaptation, as well as the institutional and technical requirements to fully leverage the capabilities of EO for adaptation planning and implementation at the national level.

**Part II: EO for Agriculture and Food Security** – This section focusses on the application of EO to support climate adaptation in the agriculture sector. It draws upon many practical examples of what has worked in places that have already adopted EO-based monitoring frameworks for agriculture. The section is structured to:

- Make the case for agriculture monitoring systems as an adaptation measure;
- Identify the variables essential for agriculture monitoring and the open science resources including datasets and tools available to countries to generate them;
- Identify the technical and institutional requirements for establishing a sustainable national EO-monitoring system;
- Identify the capacity (co-)development approach necessary to support uptake of EO; and
- Identify the available funding opportunities to support uptake of EO.

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# List of Acronyms

<b>AMIS</b> – Agricultural Market Information System	<b>GMES</b> – Global Monitoring for Environment and Security
<b>CAS</b> – Africa Risk Capacity	<b>ICPAC</b> – IGAD Climate Prediction and Applications Center
<b>ASAP</b> – Anomaly hot Spots for Agriculture Production	<b>IGAD</b> – Intergovernmental Authority on Development
<b>ASIS</b> – Agricultural Stress Index System	<b>JRC</b> – Joint Research Center
<b>CEOS</b> – Committee on Earth Observation Satellites	<b>LDC</b> – Least Developed Country
<b>CHIRPS</b> – Climate Hazards Group Infrared Precipitation with Stations	<b>LEG</b> – LDC Expert Group
<b>CIEWS</b> – Climate Information and Early Warning Services	<b>MHEWS</b> – Multi-Hazard Early Warning System
<b>CM4EW</b> – Crop Monitor for Early Warning	<b>MINAGRI</b> – Ministry of Agriculture and Animal Resources
<b>DAP</b> – Data Analytics Platform	<b>MOA</b> – Ministry of Agriculture
<b>EACM</b> – Eastern Africa Crop Monitor	<b>NAP</b> – National Adaptation Plan
<b>EAGC</b> – Eastern Africa Grain Council	<b>NASA</b> – National Aeronautics and Space Administration
<b>EAV</b> – Essential Agriculture Variable	<b>NCC</b> – National Coordination Center
<b>EC</b> – European Commission	<b>NDVI</b> – Normalized Difference Vegetation Index
<b>ECV</b> – Essential Climate Variable	<b>NECOG</b> – National Emergency Coordination and Operations Center
<b>EO</b> – Earth Observation	<b>NFSD</b> – National Food Security Division
<b>EWX</b> – Early Warning Explorer	<b>NOAA</b> – National Oceanic Atmospheric Administration
<b>EWS</b> – Early Warning System	<b>NUSAF</b> – Northern Uganda Social Action Fund
<b>FAO</b> – Food and Agriculture Organization	<b>OPM</b> – Office of the Prime Minister
<b>FEWS NET</b> – Famine Early Warning Systems Network	<b>RAB</b> – Rwanda Agricultural Board
<b>GADAS</b> – Global Agriculture and Disaster Assessment System	<b>RCMRD</b> – Regional Center for Mapping of Resources for Development
<b>GAP</b> – GIS-based Analysis Platform	<b>SDA</b> – State Department of Agriculture
<b>GCOS</b> – Global Climate Observing System	<b>UNDP</b> – United Nations Development Programme
<b>GCF</b> – Green Climate Fund	<b>UNDRR</b> – United Nations Office for Disaster Risk Reduction
<b>GEO</b> – Group on Earth Observations	<b>UNFCCC</b> – United Nations Framework Convention on Climate Change
<b>GEOGLAM</b> – Group on Earth Observations Global Agriculture Monitoring Initiative	<b>USAID</b> – United States Agency for International Development
<b>GHACOF</b> – Greater Horn of Africa Climate Outlook Forum	<b>USDA</b> – United States Department of Agriculture
<b>GHG</b> – Greenhouse Gas	<b>WFP</b> – World Food Programme
<b>GIEWS</b> – Global Information on Early Warning	<b>WMO</b> – World Meteorological Organization
<b>GIS</b> – Geographic Information System	
<b>GLAM</b> – Global Agriculture Monitoring	



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# Part I: Introduction

## 1. Earth Observations for National Adaptation Plans

Timely, accurate and long-term information is needed to inform the development and implementation of climate adaptation plans. Earth observation (EO) has long had great potential to support these needs. However, in the past, access to affordable data, insufficient historical records, spatial resolution, data bandwidth to access free and open data, computing and analytical costs have constrained practical implementation of EO based solutions. Fortunately, over the last decade, these constraints have been addressed by advances in open data access, cloud computing and free access to analytical tools. But while many of the technical barriers have come down, adoption of EO still lags in low- and middle-income countries.

EO is defined as the gathering of information about the physical, chemical, and biological systems of the planet Earth. EO data is crucial to the climate adaptation process because it provides independent, low-cost information that can be applied to identify and quantify the current state and trends in climate risks to different systems or sectors. EO provides consistent and broad spatial coverage of the Earth's systems and resources, including locations that may have been rendered inaccessible due to their remoteness and/or conflict. In addition, it offers the potential to build on measurements on the ground, also called in situ, to observe and measure a wider range of variables. Terrestrial, atmospheric and ocean EO, coupled with socio-economic data on the exposure and vulnerabilities of the human system, can help society understand the historical, current, and future risks and impacts of climate change and variability. EO information provides governments and other actors with the necessary data to underpin and inform a scientific approach for planning, implementing, and monitoring appropriate adaptation measures, and informs sustainable climate-resilient development. Ultimately, better, more timely information from EO means better, more proactive policies and programs that are more effective in terms of cost and human impact.

Notably, the full and open exchange of data and the use of ground-based and remotely-sensed observations is also critical for comprehensive risk management policies to deal with the risks associated with climate change. These policies involve risk assessment and risk reduction approaches, including the establishment of Early Warning Systems (EWS) to deliver timely, relevant, and accurate progression of hazards. A people-centered EWS comprises four key elements: knowledge of the risks; monitoring, analysis and forecasting of the hazards; communication or dissemination of alerts and warnings; and local capabilities to respond to the warnings received (see [United Nations Office for Disaster Risk Reduction \(UNDRR\)](#)<sup>1</sup>).

In an increasingly interconnected world facing climate change and other threats, Multi-Hazard Early Warning Systems (MHEWS) that cover a range of hazards and impacts are needed. They are designed to be used in multi-hazard contexts where hazardous events may occur simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects (see [World Meteorological Organization \(WMO\)](#)<sup>2</sup>). These are all critical elements that EO can support.

As such, the establishment of EO-based monitoring systems is essential for adaptation, applicable to observing climate impacts and risks on key sectors, supporting EWS and MHEWS, and monitoring how adaptation actions improve the resilience of a country over time.



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Furthermore, EO can support the development of sound adaptation projects. Many climate financing institutions such as the [Green Climate Fund \(GCF\)](#)<sup>3</sup> require those seeking funds to provide a scientific justification for their proposed climate action investments, plans and policies, including climate scenarios and prioritization of adaptation measures, something that is well within the capabilities and applications of EO. These funding institutions also use EO as part of their climate screening tools for such projects, helping them make informed funding decisions.

The [Group on Earth Observations \(GEO\)](#)<sup>4</sup> supports coordinated and open EO to support better decision making and shape more effective global, national, and local climate policies. GEO members and partners lead over 60 joint activities spanning multiple areas. Overall, these activities include approximately 7000 data providers and millions of data resources that are free and accessible to all. GEO aims to provide support to Least Developed Countries (LDCs) and other developing countries to identify opportunities offered by EO technology to integrate ground-based and space-based data and information to support the formulation and implementation of National Adaptation Plans (NAPs).

This first edition of the GEO supplementary technical guidelines on NAPs addresses EO solutions to agriculture and food security-related challenges, which will help countries with practical guidance and opportunities to drive the implementation of their adaptation agenda, based on the experience of the [GEO Global Agricultural Monitoring \(GEOGLAM\)](#)<sup>5</sup> initiative. GEOGLAM has successfully co-designed national crop monitoring systems that provide early warnings and trigger disaster risk financing mechanisms, efficiently tackling adaptation and loss and damage with EO methodologies and data embedded in institutional systems in some LDCs.

The target audience for the GEO supplementary technical guidelines on NAPs includes government agencies responsible for agriculture production, planning, statistics, and emergency response, such as Ministries of Agriculture, Environment and Public Safety. It can also support international organizations and NGOs in their response to emerging food security concerns.

While it builds on the [2012 technical guidelines by the United Nations Framework Convention on Climate Change \(UNFCCC\) LDC Expert Group \(LEG\)](#)<sup>6</sup> for the formulation of NAPs, the GEO supplementary technical guidelines focus on the technical and institutional resources required for the successful implementation of NAPs.

This first edition will be followed by other sectoral guidelines addressing key issues or themes in the NAP process with the use of EO.

## 2. Essential Variables on and for Climate Change Adaptation

Essential Variables (EVs) simply define those elements that are fundamental for the characterization of different facets of the Earth's systems, without significantly losing information on the historical or future trends of such a system (see [Giuliani et al.](#)<sup>7</sup>; and [NASA EarthData](#))<sup>8</sup>. EVs characterize the state of ecosystems with a relatively simple suite of variables, linking environmental policy indicators to relevant data sources. In application, EVs represent fundamental information which can be brought together to create knowledge to support a wide range of policy challenges. Consequently, the EV concept is useful to guide the development of EO-based monitoring systems to address climate change adaptation. A consistent application of the EV concept may also offer an avenue for the integration of information across multiple sectors. Since many policy questions require integrated analysis from multiple science domains, this approach can help reduce the complexity of analysis and streamline integration. At a practical level EVs help to support adequate observations in consideration of limited budgets, and they also help enhance the definition/scope and maintenance of workflows, converting raw data into final/end-user ready products.

Requirements for observing EVs are harmonized through expert scientific and technical reviews to match them with the capabilities of existing EO missions. As such, countries developing adaptation programs and policies can benefit from an existing body of work. So far, different stakeholders have led the development of essential variables for many sectors. Going back a decade, this approach was first initiated with the development of [Essential Climate Variables \(ECVs\)](#)<sup>9</sup> by the [Global Climate Observing System \(GCOS\)](#)<sup>10</sup> community. Since the ECVs, several other communities have developed their own set of EVs, including agriculture (EAVs), biodiversity (EBVs), oceans (EOVs), urban (EUVs), renewable energy (EREVs), mountains (EMVs), water resources (EWWs) and geodiversity (EGVs) systems.

Part II of this guidance document will focus on the work and experiences of the GEOGLAM community to develop EAVs to support climate adaptation.

Photo credit: Paul Desanker



### 3. Institutional and Technical Requirements to Access and Use Earth Observations at the National Level

Developing and operating a national EO-based monitoring framework requires a strong and adaptive institutional setup to provide a conducive and enabling environment for data provision, product development, and decision making. In conjunction, a robust technical framing, backed by relevant expertise from different fields, is paramount for governments to successfully leverage EO capabilities. The institutions lay the foundation for, and offer a home to, the technical infrastructure and personnel, providing the operational lifeline for EO integration into policy planning and other sectors of national governance.

A capacity development strategy is also crucial and necessary for building new and/or enhancing existing institutional and technical capacities of all the stakeholders. These elements are discussed in the following section.

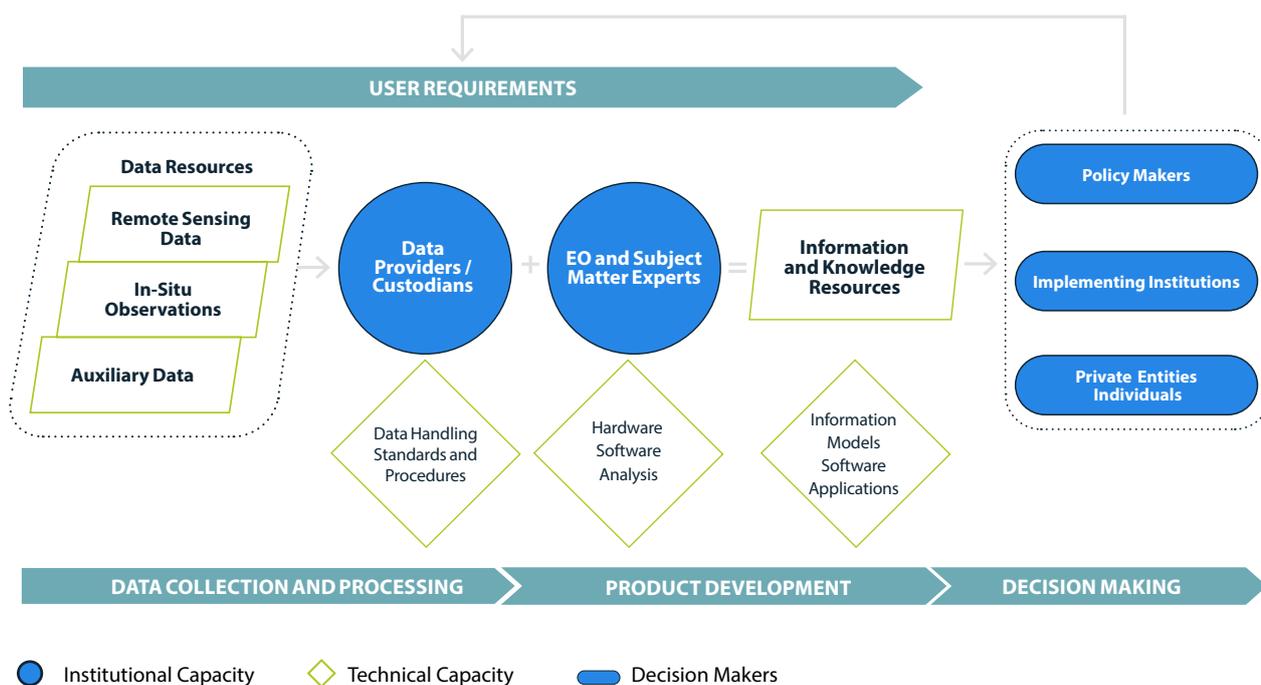
#### 3.1 Data Collection and Processing

On the data supply side of a national EO-based monitoring framework, the primary contributors are satellite data providers, including the public space agencies of the world for free and open data, and commercial satellite providers, for high-resolution

data usually at cost. In situ or field observations that are essential to the system are usually collected by or on behalf of the host country. Beyond EO, analytical operations are also augmented by ancillary data, including demography, sectoral information, and other socio-economic statistics. These data providers may also double as the custodians of data.

National EO monitoring systems need to process large satellite datasets, particularly for sectors that require the processing of data at multiple time steps through a given period, such as monitoring crops through the growing season. In countries with low and/or expensive internet bandwidth, downloading big data can be time and cost prohibitive. In recent years cloud computing services have developed. These services provide secure environments to move analytical processes and relatively small in situ calibration/validation data to satellite data archives. This significantly reduces the cost of data transfer, and it also reduces the cost of computing time because the user only pays for the processing time required to complete their analysis. Cloud computing also enables sharing and reuse of analytical software and applications, which are more openly available.

Figure 1 - General architecture of an EO-based monitoring framework



### 3.2 Product Development

The next group of contributors includes the EO experts who are responsible for data processing, manipulation, and product development. These are assisted closely by academia and other research institutions whose main contributions are research and capacity development oriented in the EO field. Product development should always be guided by the best available practice, tools and technology as well as the intended end-use/application. Thus, it is critical to work in close consultation with the subject matter experts, such as agriculturalists, to develop products for agriculture monitoring. This collaboration will help enhance product interpretation accuracy and consequently, the accuracy and reliability of the generated information for decision making purposes. Subject matter experts also work together with the other actors to analyze and interpret the results produced, and help translate them, with the help of communication and knowledge managers, into useful and practical information and knowledge products readily applicable to support decision making by the user communities. Over the last decade there has been a considerable amount of development on openly available analytical tools and platforms that can significantly lower the cost of expertise for adopting countries.

### 3.3 Decision Making

In the EO architecture, end users may include any person(s) or entity(ies) in a decision making role/capacity. They include policy design experts or bodies, institutions responsible for program/project implementation as well as the private sector, including private individuals and organizations. Policy and other decision makers may solicit the advice and recommendations of subject matter experts to design proper and impactful action plans or policies.

### 3.4 Capacity Development

Early warning of impacts of climatic events can provide a valuable tool for countries to adapt and respond to emerging challenges. Experience has demonstrated that when countries operate their own EO-based monitoring systems, the information is trusted and as such generally turned into program and policy response decisions faster, compared to information from external sources. Country-generated decision support information also benefits from more local and regional expert input

because they can exploit existing networks, extension services, and government programs. With respect to climate adaptation, rapid response is often critical. Acting in advance of climate disasters is more effective and less costly than reactive response after the disaster.

Consequently, it is important that the technical partner institutions work with countries to co-develop or co-create internal processes through which national organisations and institutions obtain, strengthen, and maintain their EO capabilities for responding to climate events.

This approach is advantageous because it is based on equally shared partnership, ownership, and responsibility, which inspires and encourages active engagement of all involved. Co-development also helps to highlight and position the needs and considerations of the benefitting party at the center of the program, ensuring interventions are fit-for-purpose and that maximum value is achieved as a result. All these merit greater uptake and leveraging of EO for increased societal impact.

Figure 2 - Fit-for-use design of an EO-based monitoring framework

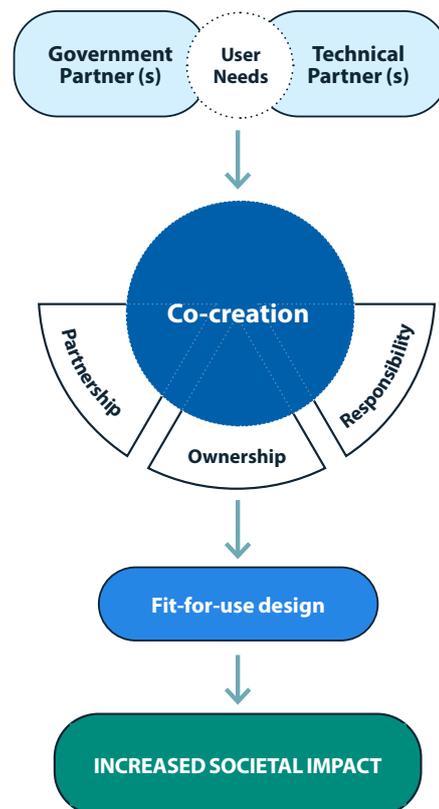




Photo credit: Unsplash - Gabriel Jimenez

# Part II: Earth Observations for Agriculture and Food Security

## 1. Agriculture and Food Security

The increasing frequency and severity of extreme events and their impacts are being felt in many regions of the world. The severity of these impacts is more significant in smallholder crop and livestock production systems in low-income countries, which are often less resilient to climate extremes<sup>11</sup>. Timely access to actionable information on the impact of climate on food production can provide critical information to national adaptation policies and programs (see [Becker-Reshef et al.](#))<sup>12</sup>. Early warning can provide decision makers at all levels with the ability to target proactive actions that can reduce harm while reducing costs compared to reactive solutions. Beyond increases in extremes, changes to climate norms that take place over years and decades also impact the sustainability and resilience of agricultural systems (see [UNFCCC](#))<sup>13</sup>.

While key adaptation measures for short-term extremes include early warning, long-term changes require dedicated monitoring programs that measure the state and changes in the agricultural landscape. Monitoring and measuring these changes using EO can open the doors to longer-term adaptation measures at various scales ranging from sector-wide changes aimed at developing a more climate-resilient agriculture sector (for instance, trade policies, government programs, insurance options, and technologies), to site-specific responses (for instance, inputs, tillage, seed selection, crop rotations, and harvest strategies) (see [Janowiak et al.](#))<sup>14</sup>. The information derived from EO may be applied to assess threats to agricultural production, such as extreme climate and weather events, and other anthropogenic stressors, such as conflict. These threat and impact assessments can help in the design and implementation of policies and programs, including action plans to adapt agricultural activities to build resilience and effectively respond to change.

This document has been prepared to summarize critical steps in setting up the technical and institutional infrastructure for EO-enabled crop monitoring and EWS.

Photo credit: Paul Desanker



## 2. Earth Observations for Agriculture Monitoring

Satellite EO data is an essential source of information for forecasting, tracking, measuring, and responding to short and long-term climate-related impacts (see [Committee on Earth Observation Satellites \(CEOS\)](#))<sup>15</sup>. In the last decade, the availability of openly available satellite EO and open science has expanded at unprecedented rates and this trend towards open science will continue.

Enhanced data availability, improved crop monitoring methodologies, increased access to cloud computing platforms, and investments in research and operational programs are lowering the cost and technological barriers, generating opportunities for adapting systems for local needs.

Since the 1960s, EO satellites have been gathering information about the planet's physical, chemical, and biological systems. Remote sensing is used to detect and monitor an area's physical characteristics by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). The sensors on satellites

provide high-quality imagery of the surface of the Earth. These images can provide many types of essential information on agriculture, collected at different points in time, that address relevant policy questions about the sector. These images are analyzed using ground data to train models to extract information on what crops are growing, where they are growing, their current condition, and forecasted yield. Site-specific information can inform on-farm management decisions. Most critically and relevant for national climate adaptation planning, geographically disaggregated information can inform better policy planning to optimize and promote climate-smart agricultural practices and early warning on impending disasters.

Photo credit: Canva/PeterAustin/GettyImagesSignature

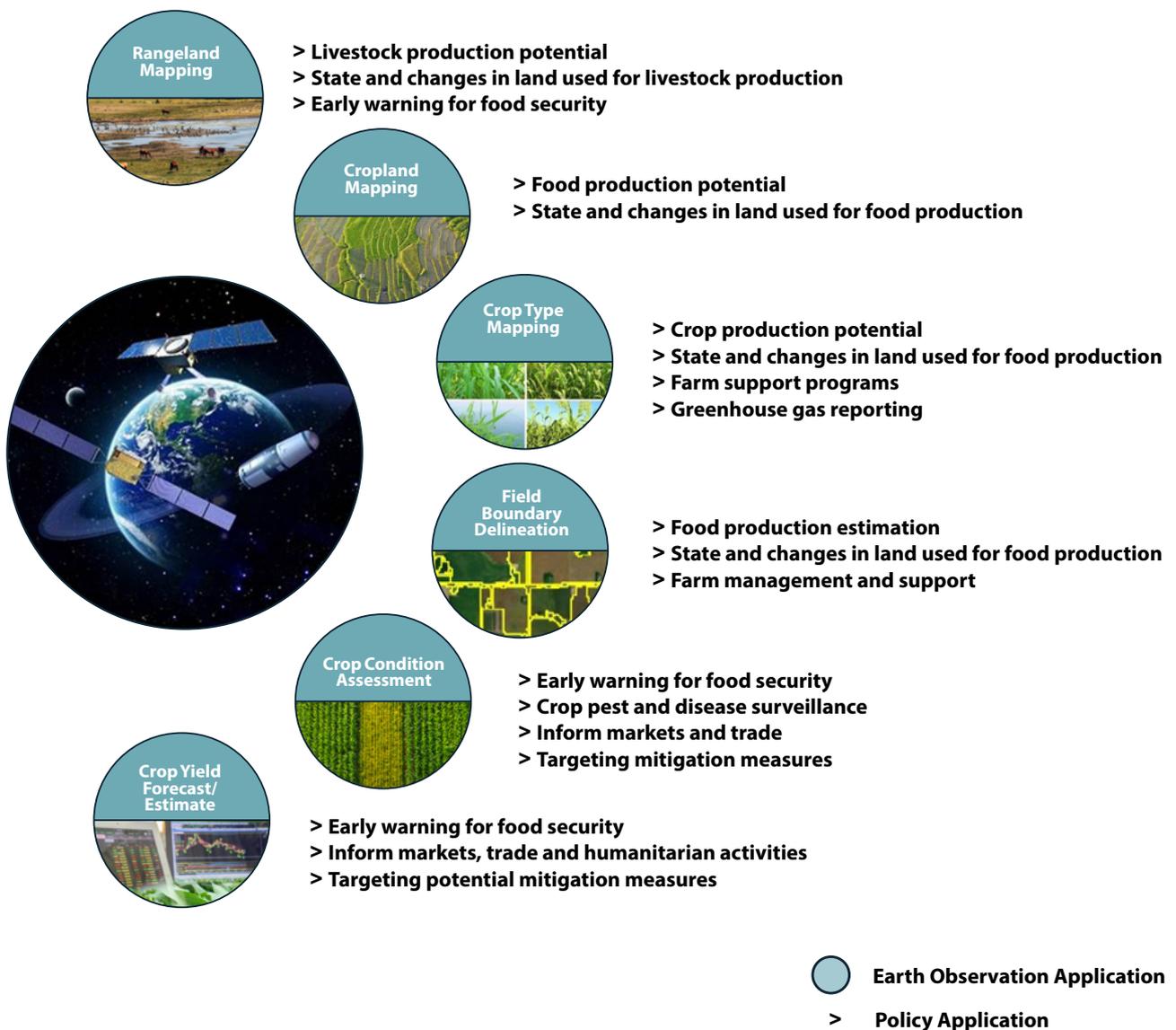


## Box A: EO Capabilities for Agriculture

Fundamental agriculture-specific questions that can be answered with EO include:

- What are the current crop conditions?
- What are the prospects for agricultural production?
- What are the current and forecasted weather and climatic conditions and their potential impacts on agricultural production?
- How are these conditions likely to change in the future?
- How will these changes affect agricultural land use, management, and overall production prospects?

Figure 3 - Essential EO Information and Applications from Agriculture Monitoring



Moreover, climate risk assessment reports can provide critical information for agricultural insurance strategies in a bid to reduce or manage eminent disasters. Crop and livestock insurance are some of the areas that have piqued the attention of most agriculture and food security practitioners and governments. The [Africa Risk Capacity \(ARC\)](#)<sup>16</sup> and the [Pacific Insurance and Climate Adaptation Programme](#)<sup>17</sup> are regional examples where the application of EO is central to the adaptation of agricultural programs. ARC, for instance, uses advanced satellite weather surveillance to predict and estimate the level of damage from a disaster event (to agriculture systems) to help trigger the rapid release of funds to enable governments to proactively respond with appropriate measures. Madagascar, Zambia, and Malawi are some of the recent beneficiaries of the ARC facility, helping them respond proactively to drought risk, and thus, increasing their resilience and saving economic resources that would otherwise be expended on reactive drought response efforts.

Like these, there are now many examples of where EO has been deployed successfully and these supplementary guidelines will use several cases to demonstrate opportunities for countries drafting their NAPs.

Box B provides an example where an adaptation in agricultural management practices can increase resilience to climate change while mitigating greenhouse gas (GHG) emissions and increase food production.

### **Box B: Rice Production Water Management: Climate Adaptation-Mitigation Co-benefits with EO**

Rice is the staple food for over half the world's population, providing up to 50% of the global dietary caloric supply. Methane, a significant GHG, is produced during rice production, and is responsible for a significant contribution to global GHG levels. Current emissions amount to around 1.5% of total anthropogenic emissions, and this could increase as more rice is produced to support the growing population. Fortunately, improvements in water management practices, like mid-season drawdown and dry seeding, can increase resilience to drought while reducing water consumption. The practice also has co-benefits of boosting rice yields and reducing methane emissions. In this way countries can use EO to target their policies to lands where adaptation best practices can be introduced, quantify the positive impacts of the changes in terms of GHG mitigation, and increased food production (see [Mofijul Islam et al.](#))<sup>18</sup>.

Another example of how EO based agriculture monitoring can support national food security programs is provided in Box C. It highlights an application of EO in food security emergency response during after cyclone disaster event in Mozambique, leveraging the technical and institutional capacities of the stakeholders involved.

Photo credit: Unsplash - Tim Shepherd

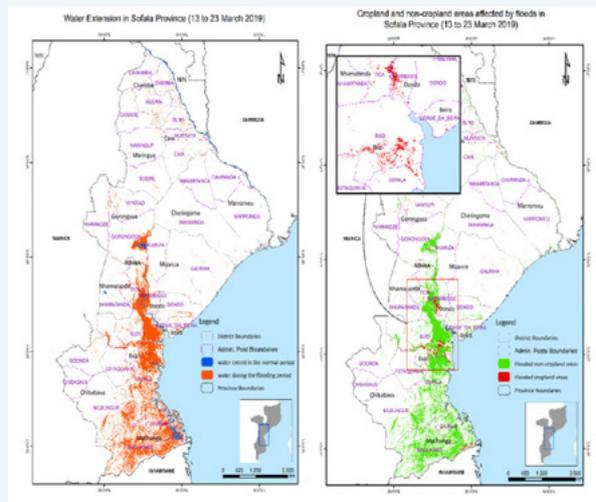


## Box C: Monitoring flooded cropland in Mozambique – Cyclone Idai Response

EO can provide an effective tool to adapt to climate extremes by providing information that supports effective response. In early March 2019, heavy rains inundated Mozambique, causing deadly floods. The storm soon developed into tropical Cyclone Idai, affecting an estimated 1.8 million people, and destroying thousands of livelihoods. 90% of the communities rely on agriculture as their main livelihood source, with livestock rearing and fishing coming in second and third, respectively. Farmers reported up to 50% reductions in crop harvest post-cyclone, mostly due to high winds and flooding of agricultural fields.

The Ministry of Agriculture and Food Security, in a co-development frame with CropWatch, a GEOGLAM partner, worked together to create flood maps to track the impact of the disaster on agricultural production. The analysis used cloud-penetrating Sentinel 1 satellite imagery to accurately map out the inundated areas in near real-time. This information was complemented with daily rainfall data and cropland maps for each of the affected districts, helping the Ministry of Agriculture to understand the extent of flooded cropland, and to effectively target food security response to such areas.

Figure 4 - Examples of flood extent maps produced to assess the impact of cyclone-induced floods on agricultural fields



**Lead Agency:** Ministry of Agriculture and Food Security

**Data:** Sentinel 1, Rainfall statistics, cropland maps

**Systems Utilized:** CropWatch

**Products:** Cropland Flood extent maps

**Co-development Partners:** GEOGLAM- CropWatch

### 3. Identifying Essential Information for a National Agriculture Monitoring System

The GEOGLAM community has defined a set of [Essential Agriculture Variables \(EAVs\)](#)<sup>19</sup> that can be generated by EO data to support agriculture monitoring. Table 1 lists some of the key climate adaptation mapping variables for agriculture. Many EO-based information products, and/or analysis tools, for these variables are openly available for countries to use, and several of these are listed in Appendix B. In application, EAVs can be used to develop NAPs, and implement and monitor adaptation measures. For example, they can be used to generate crop growth indicators to determine the condition of crops in near real-time, throughout the growing season. This information can be used to anticipate crop production and provide early warning on the impact of emerging climate extremes on crop yields, an important climate adaptation measure.

Agriculture is sensitive to extreme weather and climate variability. ECVs<sup>9</sup> make an important contribution to agriculture monitoring and several ECVs are considered EAVs. The ECVs that are most significant to agricultural production include, but are not limited to, rainfall, temperature, solar radiation, wind speed and direction,

humidity, soil moisture, and evapotranspiration. GCOS has made great strides in producing openly and freely available data resources around the ECVs and measuring these variables using EO has evolved rapidly in recent years. This includes access to datasets, information products, analytical platforms, and ready-to-use applications that are made available with little or no restrictions. CEOS maintains an [ECV inventory](#)<sup>20</sup> that provides a gateway to this information. These open science resources have lowered the bar to adoption by reducing the cost and expertise required for uptake. Near real-time EO measurements of current conditions and historical observations can be used to depict trends over time (see Appendix D).

In summary, EAVs and ECVs provide open resources for any country interested in developing, implementing, and monitoring agriculture within the NAP framework. Countries can leverage the work that has taken place in these communities, streamlining uptake, while benefiting from global scientific expertise and billions in investments in space-based EO missions.

Table 1 - Essential Agriculture Variables

VARIABLE	DEFINITION
<b>Cropland / crop-type map/ crop-type mask</b>	A map showing land devoted to crop cultivation or the extent of cropland. Crop masks differentiated by specific crop types are referred to as crop-type maps.
<b>Crop condition indicators</b>	Crop condition indicators like the Normalized Difference Vegetation Index (NDVI) serve as the basis for crop condition monitoring, providing information on crop development and vigor. These indicators typically provide information, through time, related to crop status and biomass, weather (such as temperature, rainfall), or water availability (such as soil moisture, water stress) which are all factors impacting crop growth.
<b>Crop yield forecast and estimates</b>	The amount of agricultural production harvested—crop yield per unit of land area. Using EO, yield forecasting is based on predictive models using observable indicators of crops’ progress using meteorological and remotely sensed vegetation indices. Forecasts are made within a season (pre-harvest), while estimates are done post-harvest.
<b>Rangeland mask</b>	Rangelands are areas where wild and domestic animals graze or browse on uncultivated vegetation dominated by grass-like plants, forbs, and possibly shrubs or dispersed trees.
<b>Field boundaries</b>	Geometric borders of farming fields. A field, in this case, is an area of land, enclosed or otherwise, used for agricultural purposes such as cultivating crops.

## 4. Implementing an Earth Observation-Based National Agriculture Monitoring System

### 4.1 Introduction

Under the GEOGLAM banner, international, regional, and national crop monitoring organizations came together to build the [Crop Monitor for Early Warning \(CM4EW\)](#)<sup>21</sup>. Since 2016 the CM4EW has brought EO data together with local expertise to demonstrate 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 characterized by sharing data, information, networks, and experience. Using standard definitions and criteria for crop monitoring, members of the CM4EW community build consensus on crop conditions globally through a monthly deliberative process. 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. The result is a monthly consensus assessment of food crop conditions. When observed over time, the information provides insight into food production prospects for the season, and early warning to emerging production concerns. A more detailed overview of the CM4EW system is provided in Appendix A.

Based on the success of the global CM4EW, GEOGLAM recognized the potential for regular science-based assessments toward national monitoring activities. To realize this potential, GEOGLAM has worked to support the Crop Monitor process in multiple LDCs, through various GEOGLAM contributing programs and projects. National methods are generally based on the GEOGLAM approach, but implementation is a co-development process that specifically addresses end-user organizational needs. Experience has demonstrated that when countries develop their own crop monitoring information, it is trusted and quickly applied to national program and policy decision making. A further benefit,

as Government agencies manage national crop monitoring systems, the information produced can be integrated into the CM4EW, improving the quality of regional to global food security monitoring information. Tanzania, Kenya, and Uganda have fully operational systems, and national reports are now produced regularly across these countries.

The GEOGLAM Crop Monitor approach has become an international best practice for crop condition monitoring. It has proven adaptable, scalable, and sustainable through its successful integration within regional and national contexts. Through collaboration and coordination at scale, the GEOGLAM Crop Monitors support cross-agency discussion and information sharing to support adaptation through disaster preparedness systems and processes. Specifically, as a tool for climate adaptation, the GEOGLAM Crop Monitor aims to reduce vulnerability to food production crises and increase resilience and preparedness in advance of realized impacts. The cross-agency consensus around early warning of food shocks enables proactive response that is more effective, and lower cost compared to post shock reactive responses. The net result is reduced vulnerability and enhanced resilience to climate-related extreme events along with reduced potential economic, social, and environmental shocks.

## 4.2 Key Steps to Implementing a National Agriculture Monitoring System

Implementing an EO-based monitoring system at the national level involves several steps and actions. Before getting to the actual implementation, identifying critical stakeholders, the leading agency, and mapping out capabilities, capacity, and data sources available in and for the country is of utmost importance.

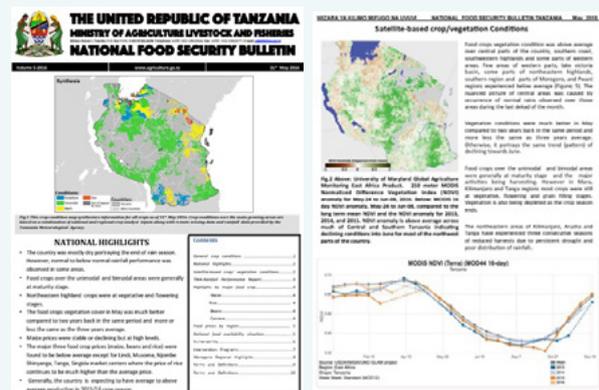
Box D provides an example of the set-up of an operational process using the Tanzania Crop Monitor, and includes the capacity development process, data sources, and integration into the government's priorities.

Another approach that can be adopted by countries is to work regionally. This can create efficiencies and reduce costs by sharing resources. Also, this approach can have side benefits since many climate-related impacts are transboundary in nature and can benefit from regional information and response. The Eastern Africa Crop Monitor (EACM) provides an example of regional implementation (Box E).

### Box D: The Tanzania Crop Monitor Set-up and Operation

The first GEOGLAM National Crop Monitor was developed with the Tanzania Ministry of Agriculture (MoA) National Food Security Division (NFSD). NFSD is mandated to monitor and report on the country's food security status. The Crop Monitors are custom-built web-GIS-based interfaces that allow analysts to access and input crop conditions assessments based on EO data and field reports that are later summarized into easily interpretable map reports. Through joint needs assessments and training events, NFSD opted to include remote sensing-based inputs to enhance their national food security bulletin, capitalizing on the fact that EO data were readily accessible from the customized version of the GLAM system for every region in the country, and combined with field observations, simple reports could be compiled using the newly developed Tanzania Crop Monitor system. The team trained on the use of remote sensing information from GLAM that complemented the ministry's existing data collection systems and, since 2015, has integrated this into regular reports from NFSD. In 2019 the NFSD team was introduced to the Early Warning eXplorer (EWX), which became a core source of data for agrometeorological indicators. EWX is a web-based single-page application for geo-spatial data mainly related to monitoring agricultural drought and providing early warning information. The EWX provides easy and routine access to critical EO with the primary goal of enhancing its application for disaster mitigation and supporting long-term adaptation and resilience. NFSD sources additional data from Tanzania's Meteorological Authority and the Ministry of Trade.

Figure 5 - Example of National Food Security Bulletin for Tanzania produced by the Ministry of Agriculture, Livestock and Fisheries



**Lead agency:** Ministry of Agriculture, Tanzania

**Supporting University:** Sokoine University of Agriculture

**Product:** National Food Security Bulletin

**Systems utilized:** GLAM, Tanzania Crop Monitor, Early Warning Explorer

**Co-development partner:** GEOGLAM-University of Maryland/ NASA Harvest

## Box E: Eastern Africa Crop Monitor

In this example, the [East African Crop Monitor](#) (EACM) makes use of EO and ground data to monitor crop conditions in the region. Agricultural monitoring is vital in detecting short-term deficits in crop productivity in response to a range of drivers, especially in areas frequently impacted by high cases of food insecurity.

This bulletin provides timely monthly warnings of agricultural production deficits (hotspots) in rain-fed systems. The example here is from the month of August 2022, a particularly challenging time due to extended drought in the region. This report is part of an operational EWS for food security crises prevention and response planning anticipation in Eastern Africa region.

**Lead agency:** IGAD Climate Prediction and Applications Center (ICPAC)

**Partners:** Eastern Africa Grain Council (EAGC). The EAGC is a grain trade, not for profit, organization focused on market constraints to trade.

**Product:** Eastern Africa Regional Food Security Bulletin

**Systems utilized:** ICPAC Crop Monitor System, GLAM, EWX, ASAP

**Co-development partner:** GEOGLAM - African Union Commission, Global Monitoring for Environment and Security (GMES) & Africa, NASA (National Aeronautics and Space Administration) Harvest/University of Maryland, SERVIR E&SA/RCMRD, JRC

**Inputs from:** The Greater Horn of Africa Climate Outlook Forums (GHACOF). The GHACOF brings together climate scientists, meteorologists, and experts from multiple sectors to evaluate potential impacts of the seasonal forecast and co-produce mitigation measures.

**Contributions from National Representatives from ICPAC member countries:** Kenya, Sudan, Uganda, Rwanda, Burundi, Ethiopia, Somalia, Djibouti, Eritrea, South Sudan and Tanzania.

Figure 6 - Example of Bulletin prepared by ICPAC for Eastern Africa



The following sections further describe the steps countries can take to set up and implement their own agriculture monitoring systems as a climate adaptation measure. The key steps are illustrated utilizing examples of workflows implemented in multiple countries. These relate to institutional and technological frameworks, as well as the capacity (co-)development opportunities and funding opportunities available for implementation.

The specific key steps to implement a national EO-based agriculture monitoring system include the following:

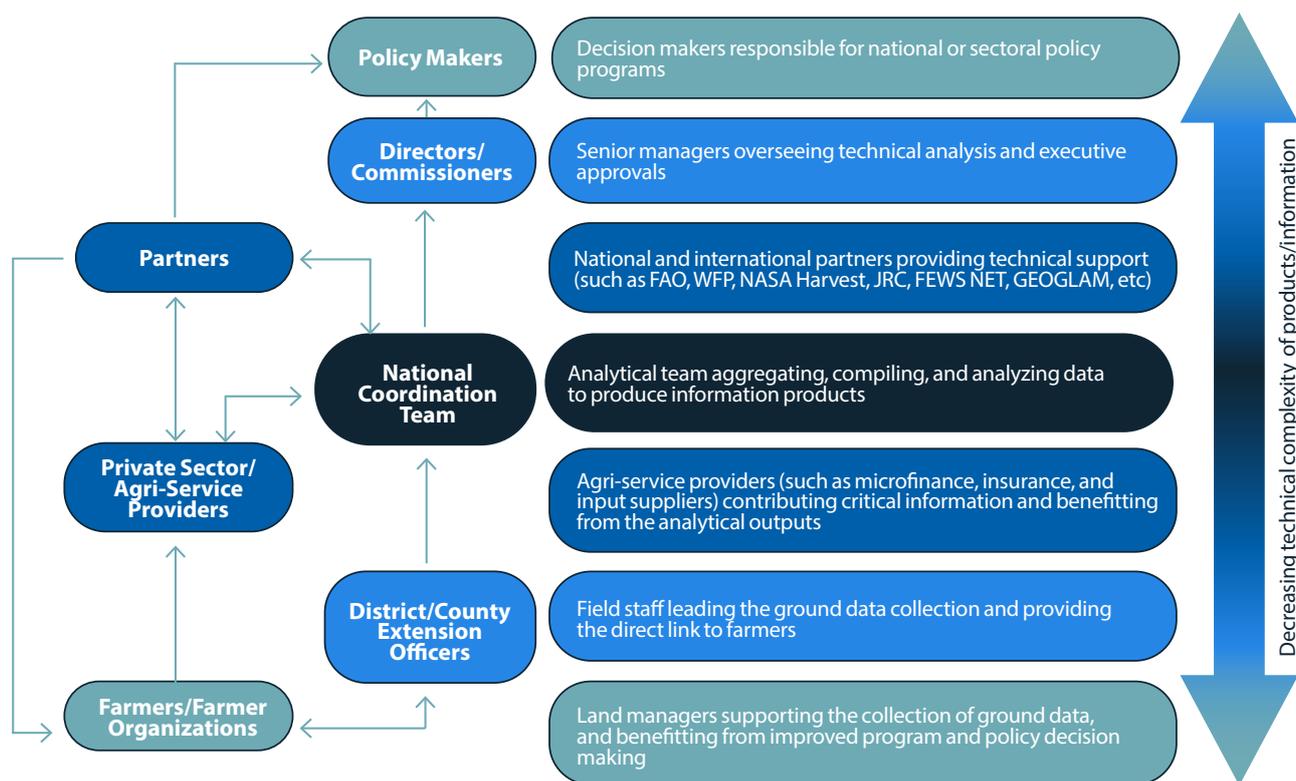
- Step 1:** Establishing the institutional framework;
- Step 2:** Establishing the technical framework;
- Step 3:** Accessing capacity (co-)development support;
- Step 4:** Accessing financial support

#### 4.2.1 Step 1: Establishing the Institutional Framework

The institutional setting within established national agencies is a core component of a successful agricultural monitoring system. This section describes the institutional framework for an operational EO-based system (Figure 7). The framework was developed based on the experience of countries with successful crop monitor implementations. While every country is unique, a few practical examples of institutional frameworks are presented as successful models.

An important step is to establish a lead agency which is home to the **National Coordination Center (NCC)**. The lead agency is often in charge of compiling and presenting evidence on crop conditions and production across the country, and usually manages the national food balance sheet, often reporting to directors that report to policymakers such as Ministers. In Kenya, this is the State Department of Agriculture (SDA) (see Box G); the National Food Security Division (NFSD) in Tanzania (see Box D);

Figure 7 - Institutional Framework for an EO-Based National Agriculture Monitoring System



the National Emergency Coordination and Operations Center (NECOC) in Uganda (see Box F and Box H); and the Ministry of Agriculture and Animal Resources (MINAGRI) in Rwanda, coordinating with Rwanda Meteorology and Rwanda Agricultural Board (RAB), among others.

The national coordination team can be multi-agency, composed of experts drawn from multiple disciplines, including agricultural monitoring, food security, statistics, and early warning. Skill sets may include crop resources assessment, pest management, agro-meteorology, GIS and remote sensing. Analytical products generated by the NCC may include food security bulletins, food balance sheets, and/or crop monitor reports.

**Directors/Commissioners** provide executive oversight of the work teams and are responsible for final approval of analytical products before they are handed off to the policy makers.

**Policy Makers** are responsible for legislation and policy direction/decisions on matters such as climate risk

financing, agricultural programming, adaptation, policy changes or scale-ups, insurance pay-outs, etc. They receive the final information products for implementation.

**Partners** include national and international technical partners that provide auxiliary data and assessments and support national programs. These may include FAO, WFP, NASAHarvest, JRC, FEWSNET, GEOGLAM, etc.

**Private sector/Agri-Service Providers** are agricultural service providers, such as microfinance, insurance, manufacturers, who can contribute critical information and benefit from reports and data accessible from or synthesized by the NCC.

**Extension Officers** have on-the-ground expertise regarding agriculture in their regions. They are ideally positioned to lead ground data collection for calibration and validation of EO based assessments. They are also the direct and most strategic link to the farmers.

**Farmers/Farmer Organizations** are the ultimate beneficiaries of the policy decisions. They can also be integral to providing farm/ground reports and data in addition to critical feedback on the effectiveness of policies and programs

The complexity of data and information flow from farmers, extension officers and other stakeholders climaxes at the level of the NCC, where data aggregation and analysis are done. This information is then sieved and transmitted further up the value chain in the form of reports and recommendations for decision making.

### Box F: Institutional Set-up for Uganda Crop Monitor

The lead agency in Uganda is the National Emergency Coordination and Operations Center (NECOC), under the Department of Disaster Preparedness, Relief, and Management (DPRM) in the Office of the Prime Minister. Uganda adopted the GEOGLAM Crop Monitor as a system for synthesizing crop conditions leveraging EO to produce the monthly National Integrated Early Warning Bulletin (U-NIEWS). NECOC officers (Disaster Management Officers) synthesize GLAM and EWX systems data to complement ground data from extension agents. These are further augmented by other auxiliary data such as meteorological reports from the Uganda National Meteorological Authority and food security status reports from relevant line ministries, including the Ministry of Agriculture and the Ministry of Health, and development partners, including the Food and Agriculture Organization (FAO), the World Food Programme (WFP), and the Famine Early Warning Systems Network (FEWS NET), to compile comprehensive assessments and reports on crop and pasture conditions, as well as information on any food security related disaster risk for early warning and mitigation. The NECOC team comprises analysts from different fields of expertise, including disaster management, GIS/Remote sensing, and agricultural officers from the Ministry of Agriculture. In the overarching framework, NECOC is the NCC, reporting to the Commissioner DPRM, who reports to the Prime Minister. NECOC also coordinates with district extension agents to collect data from the field and often carries out field-based food security assessments.

### Box G: Institutional Set-up for Kenya Crop Monitor

The Kenya Crop Monitor was customized for reporting by the State Department of Agriculture (SDA). The tool allows the SDA to assess a specific crop type at the county level and make a report on the crop condition and related drivers such as climatic conditions, extreme events or pests and diseases, and provide information on the expected outlook depending on such drivers. The input to the assessments is synthesized into the Kenya Crop Conditions Bulletin, with narratives and maps that feed into the SDA monthly reporting at the national level to inform food security decision making. The information in the report originates from national and county reports combined with EO data providing information such as greenness indices, rainfall, and soil moisture. The National Crop Monitor portal offers a central location for collecting and consolidating information from the contributing sources at the national and county levels and provides tools for synthesizing the data into usable information. The SDA liaises with county officers who provide field reports every month.

#### 4.2.2 Step 2: Establishing the Technical Framework

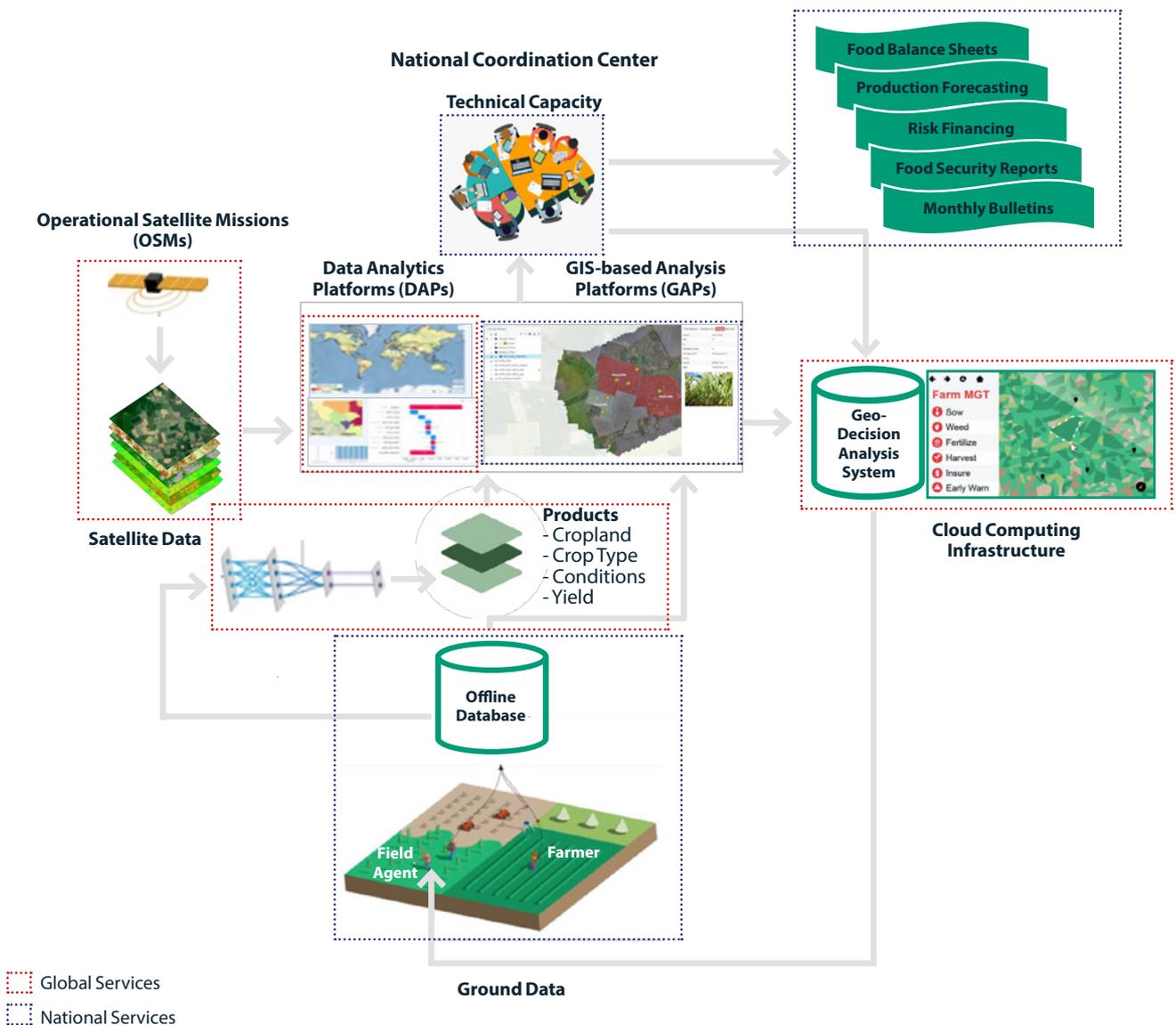
Together with the appropriate institutional framework, the technical framework can provide a roadmap for countries wishing to develop and implement their own national crop monitoring and EWS as a core component of national adaptation for agriculture.

In recent years, advances in open data, analytical tools, and computing have made the implementation of EO-based agricultural monitoring accessible to many organizations that might have been constrained by cost and capacity in the past. Based on the GEOGLAM experience in countries managing their own crop monitoring systems, as well as the Global Crop Monitor for Early Warning, GEOGLAM has identified some best practices for implementation. Figure 8 provides a schematic of these technical elements.

The backbone of a national EO-based monitoring system hosted by the NCC, or a similar institution, includes the following elements.

**Operational Satellite Missions (OSMs) for land monitoring:** Many satellite missions enable access to historical and near real-time data to derive higher-level products such as cropland and crop-type maps and vegetation conditions from indices such as the Normalized Difference Vegetation Index (NDVI). For example, the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor from NASA provides open access to daily data on land, oceans and lower atmosphere. MODIS-NDVI record dates 2000 - to date (22+ years of data) and is one of the most used datasets for assessing crop conditions. Other critical data include rainfall, including the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) dataset that incorporates satellite information to represent regions

Figure 8 - Technical Framework for an EO-Based National Agriculture Monitoring System



with sparsely distributed rain gauges. Taking advantage of data from operational systems is an absolute necessity while countries develop local capacity and satellite capabilities.

**Data Analytics Platforms (DAPs):** DAPs are EO-based agricultural monitoring platforms that primarily store and support the visualization of satellite-derived data. DAPs are used to conduct agricultural assessments, including crop conditions, yield assessments, and impacts of extreme events on cropland. They are essential for national monitoring by enabling open access to critical datasets to generate rapid analyses that would otherwise be cost-prohibitive to custom build. Web-based, open access examples are included in Appendix C. No additional hardware, software, or server space is required to operate these systems. These allow analysts to continuously assess agriculture using the best available data, knowledge, and information and provide actionable information to the decision makers, such as national governments. These systems enable governments to leverage open science resources to augment national systems, allowing countries to make significant leaps in timeliness, spatial coverage, and accuracy, that would otherwise be very costly to build from scratch. Some of the standard datasets employed in these platforms are included in Appendix D.

**Custom-built GIS-based Analysis Platforms (GAPs):** GAPs provide some customization or dedicated use of GIS software to summarize map results for reporting. Examples are the GEOGLAM Crop Monitor Systems and ground data aggregation.

**Cloud Computing Infrastructure:** Now available at relatively low cost, and augmented by workstation, internet, and mobile computing platforms that are also increasingly low cost. Cloud computing has become an essential element for in-house workflows to develop map products from raw satellite data. These allow quick data access and processing that would otherwise take months to download and are impossible to analyze without High-Performance Computing (HPC) Clusters.

**Ground data:** Ground data are required for contextualizing, informing, interpreting, and evidencing EO-based assessments. While indices like NDVI might indicate vegetation conditions, in the absence of in situ data, sometimes this can be misinterpreted or wrongly assessed. More critical, however, is that ground-based information is needed to train models used to derive the information. In the absence of ground data, analytical products will have unknown levels of uncertainty. While critical to success, ground data is also expensive to collect. Consequently, to sustain ground data efforts,

Figure 9 - Ground Data System



it is advisable to use existing national institutional and programmatic structures to minimize costs and ensure the continuity and accuracy of data collection. In this regard field, extension agents can be trained and equipped to collect the required data as part of routine activities (which they often already do).

Data should be managed through readily available and open access data collection applications that enable recording location and all other required data. For example, Kenya's Ministry of Agriculture team depends on county extension agents that collect data electronically and provide expert information needed for analysis. This data collection can be augmented with scheduled or ad-hoc field assessments. Examples of open tools for electronic data collection include [OpenDataKit](#)<sup>22</sup> and [Survey123](#)<sup>23</sup>, allowing remote submission, location data collection, and aggregation. Collecting and submitting ground data electronically provides near real-time visualization and analysis in custom aggregating systems and with GIS software. These tools allow for form customizations to meet the context, including language and reporting scales. Figure 9 summarizes how ground data are utilized within an EO-based agricultural monitoring system.

**Technical Capacity:** This is a critical enabling element that allows organizations to capitalize on the open science, data, tools, among other open resources. It is paramount that the team at the NCC is capacitated through training and recruitment and possesses the necessary skills and knowledge. To assess and analyze EO-data leveraging existing systems or using custom-built systems, no specialized remote sensing or GIS skills are required.

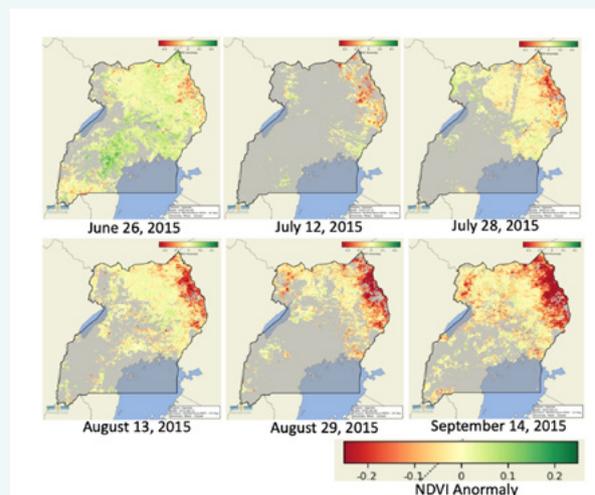
The example below (Box H) highlights an application of EO-based EWS, and its impact on emergency response in the Karamoja region of Uganda. This case provides an overview of the technical and institutional framing, and is a particularly insightful example, since a post-response study was taken to quantify the impact based on the number of households whose livelihoods and food security was positively impacted, as well as the financial cost savings accrued.

### Box H: Disaster Risk Financing Program in Uganda

#### Summary of case study subject and outcomes:

Most of Uganda's farmers are smallholders who are particularly susceptible to recurrent climatic shocks, particularly drought. To build resilience, the Ugandan Office of the Prime Minister (OPM) sought to design and implement a social safety net program for the northern Karamoja region. More than 80% of households in the region rely on rainfed, subsistence crops, and they are particularly vulnerable to food insecurity due to poor, sporadic rainfall. With funding from the World Bank, and co-development from the GEOGLAM community, the OPM designed a program to unlock disaster risk financing that relied on EO for a fair and transparent process to determine when to release risk financing depending on the severity of crop failure. In this case EO-based information provided objective indicators of crop damage and helped benefit 90,405 households under the Disaster Risk Financing Program. Between 2017 and 2020, early financing release saved the government around USD 11 million in reactive food aid costs.

Figure 10- Example NDVI maps generated from the GLAM system by the NECOC team



### Data platforms and datasets used:

The Global Agriculture Monitoring System (GLAM) is a web-based platform that enables near real-time monitoring of global croplands. Data is provided by NASA using its satellite-based optical sensor for earth and climate measurements: The Moderate Resolution Imaging Spectroradiometer (MODIS) with 250 m resolution. The system automatically aggregates satellite data on vegetation, rainfall, and temperature, which analysts use to visualize and analyze crop conditions. The Normalized Difference Vegetation Index (NDVI) generated by the GLAM provides quantitative information on vegetation conditions, allowing the OPM to predict drought-induced harvest failure and estimate the level of resulting famine several months in advance. The GLAM also allows Uganda's National Emergency Coordination and Operations Center to produce crop conditions maps (see Figure 10).

### User agencies and summary of use:

The OPM National Emergency Coordination and Operations Center (NECOC) led the Disaster Risk Financing sub-component of the safety net project. NECOC is a 24 hour, 7-days a week central facility for early warning and the coordination of emergency and crisis response and recovery action, supported by a World Bank lending operation. It was established in October 2014 with the support of the United Nations Development Programme (UNDP). An expert from UMD-NASA/Harvest program worked extensively with the OPM over the project period to co-develop the Disaster Risk Financing mechanism, including providing the analysis to establish the threshold value of the NDVI, setting up the OpenDataKit for in situ data, and providing relevant training to the NECOC team.

Within Uganda, in addition to the leadership and participation of OPM and the District Agriculture Office, national and international partners actively contributed to the project. For the Disaster Risk Financing, a working group was set up and participated in by FEWS NET, FAO, WFP, and Makerere University, with inputs from the Uganda National Meteorological Authority. NECOC assessments are submitted to the Ministry of Finance, Planning and Economic Development for program implementation.

### Results and impact:

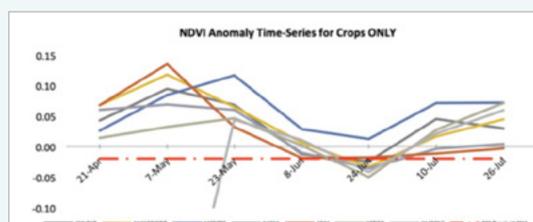
The Uganda Crop Monitor System meets the government's need for objective evidence to inform rapid and transparent responses to drought and other threats to food security. Historical data from the GLAM allowed the OPM to set a predetermined NDVI threshold value to trigger a scale-up of the Disaster Risk Financing. When the NDVI values drop below this threshold, OPM officers can estimate how much to invest in public works to provide additional employment opportunities for vulnerable communities. At the end of the growing season, NECOC used the system to calculate the number of households affected by drought, the estimated coverage of the social safety net program, and the estimated costs for each district. The government used this evidence to make the final financing decisions.

In June 2017, for example, the NDVI value dropped below the threshold in five out of seven districts in Karamoja, predicting widespread crop failure in the harvest season.

Equipped with this evidence, the government had sufficient time to take proactive action for Disaster Risk Financing. The government released USD 4.1 million to scale-up public works, benefiting 28,601 households, which translates to approximately 150,000 people, more than 50% of whom were women. This approach saved USD 2.6 million in costs for food aid, which could be repurposed to strengthening household food security.

Between 2017 and 2020, USD 14 million of financing indirectly benefitted 90,405 households in northeastern Uganda. Over the four years, the early financing release saved the government roughly USD 11 million in reactive food aid costs. The EO-based EWS has helped vulnerable households and enabled the government to plan its budget and ensure that resources are utilized efficiently and effectively.

Figure 11 - NDVI Anomaly Time-Series for Crops indicators in Karamoja's seven districts in the growing season in 2016



### 4.2.3 Step 3: Accessing Capacity Development Support

Capacity development is integral to achieving empowering transformations across any development sphere, helping individuals, organizations, and communities drive valuable and sustained impacts through the co-creation of information for decision making.

GEOGLAM aims to enhance national agricultural reporting systems. Recognizing that countries operate different systems and have different capacities to utilize EO, GEOGLAM partners support various programs and capacity development initiatives. While this work is ongoing, GEOGLAM's capacity development approach emphasizes and promotes collaboration and co-development among its partners and other stakeholders.

Through this process, organizations and institutions can obtain, merge, strengthen and maintain their EO capacities and capabilities for sustainable agricultural development and responding to challenges associated with agricultural production and food insecurity. The needs, ambitions, knowledge, and specific expertise of participating parties are recognized and positioned at the center of all engagements. This process is achieved through equal partnership, shared ownership, joint responsibility, and comprehensive stakeholder engagement.

### Box I: Capacity Development in GEOGLAM

Capacity development support by GEOGLAM aims to increase the technical and human capacity of individuals, organizations, and institutions to:

- Fully utilize EO in agriculture-related decision making processes
- Adapt organizational workflows to exploit or improve the use of EO in agriculture
- Share good practices that showcase the value of EO
- Promote the engagement of institutional users
- Strengthen the ecosystem in which the individual and organizations operate

The guiding principles of this strategy reflect GEOGLAM's core values that promote a comprehensive approach in conducting any engagements among the stakeholders. GEOGLAM's capacity development activities seek to leverage existing capacities and strengthen participating institutions, continue to develop demand-driven and impact-oriented initiatives co-developed with end-users, and produce solutions that are fit for purpose.

The figure below highlights these principles.

Figure 12 - GEOGLAM's Principles for Capacity Development (adapted from the Digital Earth Africa capacity development strategy)



**Leveraging existing capacities** and strengthening those of participating institutions in terms of human skills and knowledge as well as institutional capabilities. This can be achieved by assessing the individual and organizational needs and bridging the gap between already existing and required competencies. It serves to leverage and increase the uptake of EO.

**Demand-driven and impact-oriented** interventions, using different frameworks and activities to assess and understand specific demand(s) and desired impact(s), both in the short- and long-term. This principle is often informed via National Needs Assessments or similar undertakings and emphasizes the need to build on and strengthen the core needs of national systems.

**Co-creation and co-design** encourage the merging and matching of supply and demand in capacity development efforts, helping participating actors to derive real and measurable impacts jointly and in a holistic manner. Co-development of strategies and interventions creates an added value to capacity development efforts that might have otherwise been more of unidirectional information sharing exercises.

A **Fit-for-purpose approach** requires a clear understanding of the specific needs of the different audiences and builds upon existing capabilities. The “uniqueness” of the participating public and private institutions does not allow a one-size-fits-all development process, thus requiring that each of the identified audiences become part of the targeted capacity development interventions and addressed according to their role, needs, capacity, interest and influence.

**Stakeholder engagement** ranging from hands-on users of EO to high-ranking political actors should be exercised in all capacity development activities including technical, political, and personal, based on the specific roles they hold, their interests as well as influences.

**Sustainability** - organizational, technical, financial, and academic - of capacity development can be achieved in several ways. These include 1) political buy-in within the regional and international geospatial community, 2) the development of institutional and technical frameworks that fit within the existing organizational structures of the requester, enhancing the likelihood of post-project relevance and sustainability, 3) the development of a sustainable business and financial plan, 4) the establishment of secure networks for information and knowledge sharing, 5) the updating of relevant technical infrastructures, and 6) the non-cessation of all contact at project close.

**Social inclusion, diversity, and equity** help reduce bias among participating entities, improving the ability, opportunity, and dignity of all those involved regardless of their identity, role and contribution.

Photo credit: Canva/PeterAustin/GettyImagesSignature



#### 4.2.4 Step 4: Accessing Financial Support

Financial support is necessary to fully implement and sustain a national agriculture monitoring system over time. Countries can access multiple sources of national and international finance, including the GCF.

GCF's projects are aimed at achieving maximum impact in the developing world and supporting paradigm shifts in both mitigation and adaptation, notably through approaches that invest systematically in the value chain of climate information services, MHEWS, and early action capacity. Recent guidance by GCF describes three distinct pathways that can deliver significant and paradigm shifting impact: (1) strengthening climate information services, (2) promoting impact-based MHEWS and early action, and (3) improving Climate Information and Early Warning Systems (CIEWS) for investment and financial decisions (see [GCF](#))<sup>3</sup>. EO-based monitoring systems in agriculture are to be considered part of the CIEWS approach that GCF promotes.

While early warning is a top priority in LDCs and other developing countries' national climate policies, and all NAPs prepared to date mention EWS to support adaptation efforts - notably in agriculture and food security (46%) -, significant gaps remain in the implementation or upgrade of existing MHEWS (see [GCF](#))<sup>3</sup>.

To establish national EO-based monitoring systems for agriculture and food security that are embedded into the NAP process, countries may explore appropriate GCF funding windows, based on the specific steps.

In this context, technical support for developing countries to co-develop such EO-based monitoring systems is available through GEOGLAM partners worldwide. For instance, the national crop monitoring system developed in Uganda was co-designed by national authorities and GEOGLAM partners and financed through the World Bank. A similar model could be adopted in other countries to access GCF funding through national or international accredited entities, where GEOGLAM experts would act as technical partners supporting the design of the project concept and full proposal, and later the implementation.

A multi-country or regional approach could also be considered as way to address transboundary risks and interdependencies associated with international trade of agricultural produce, which would improve efficiencies to a major public funder such as the GCF.

Larger-scale interventions have also the advantage of attracting private sector investments, like commercial satellite providers, cloud services or agricultural finance and insurance, which would in turn ensure that adaptation activities are self-sustainable over time (see Box J).

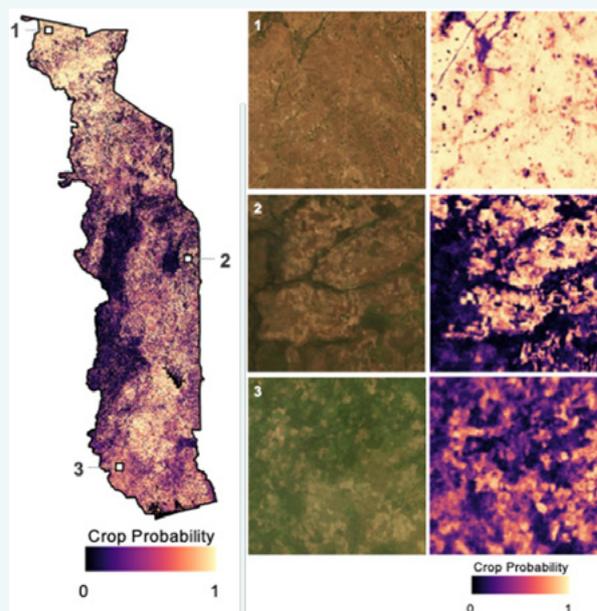
#### Box J: Rapid Response to Ripple Effects of COVID-19: Food Security in Togo

The COVID-19 pandemic has had far-reaching effects on not only human health, but also economic impacts around the world due to the severe disruption of our daily lives.

Partnering with Planet that made available high-resolution SkySat imagery, the NASA Harvest team developed a cropland map for Togo within 10 days. This map complemented poverty and census data to support rapid scaling of the Togolese government programs YOLIM - a digital and interest-free loan program intended to improve yield and livelihoods of Togolese farmers.

The map produced by NASA Harvest "provides unmatched clarity into the nature and distribution of agricultural land nationwide," stated Cina Lawson, Minister of Posts, Digital Economy, and Technological Innovation of Togo. "On top of this map, we are overlaying data from poverty maps that we have developed in collaboration with UC Berkeley's Data-Intensive Development Lab and Innovations for Poverty Action. Together, they provide decisive knowledge being used to design social protection policies aimed at improving the livelihoods of agrarian rural communities."

Figure 13 - Cropland map of Togo (2019), created with Sentinel-2 and Planet data using machine learning to support Togo's YOLIM program



(Source: NASA/NASA Harvest/Planet)

## 5. Bringing it all Together under National Adaptation Plans

While crop failure can have devastating impacts on farmers' livelihoods and food security, early warning using near real-time spatially disaggregated EO data gives governments time to prepare, mitigate and respond to a crisis to alleviate loss and damage in a transparent, cost-effective, and efficient manner. The monitoring system driven by EO and in situ observations enables fast analysis that could help mitigate climate risks.

Open data and analyses from the EO community ensure that all governments, organizations, and individuals have access to the data and information they need to report on crop conditions and manage disaster response, including disaster financing, regularly. Countries can use EO-based tools and services provided by GEOGLAM to improve lives, save money, and enhance food security. Notably, this methodology and related applications can be efficient when integrated into NAPs and policy processes to increase the resilience of the agriculture sector to climate impacts.

When bound together by co-development and funding, these elements enable sustainable national monitoring systems that produce timely, relevant, and accurate information.

Several practical examples have been presented, and Table 2 summarizes current technical and institutional set-ups in the countries discussed. The information

produced by national systems is trusted and authoritative, essential to ensure rapid utilization in the development of proactive adaptation policies and the implementation of response programs to support enhanced food security. Consequently, systems must be operated by national organizations within the country.

Building on the success and experiences so far, GEOGLAM welcomes the opportunity to work with countries looking to develop crop monitoring as part of their climate adaptation agenda, from the design to the implementation of adaptation measures in the agriculture sector.

In conclusion, improved national agriculture monitoring can play an important role in global food security. As more countries adopt processes that utilize similar methodologies, increased regional and international integration becomes possible to address multiple complex challenges that face the agriculture sector. In this regard, EO presents additional advantages to bringing nations and regions together. The formation of the GEOGLAM community of practice is founded on this premise. Regionally and internationally coordinated efforts are central to this. Also critical is to build up national capacities to support better policy decisions at home, and ultimately improve the quality of information flowing into global systems like the CM4EW.

Table 2 - Current crop monitor set-up with examples from Kenya, Rwanda, Uganda and Tanzania

COUNTRY	NATIONAL COORDINATION	ANALYTICS PLATFORMS UTILIZED	GROUND DATA / TOOLS AND TEAMS	MAIN PUBLICATION / PROGRAMS SUPPORTED / ACCESS TO REPORTS
 Kenya	State Department of Agriculture, Ministry of Agriculture, coordinating with County Extension Officers	GLAM, EWX, Custom-built Kenya Crop Monitor Kenya, Weather Forecasts from Meteorological Department	Via County Extension Officers	Kenya Crop Conditions Bulletin, Crop Insurance Program, Rapid Response to Pest/Disease Infestations
 Uganda	National Emergency Coordination and Early Warning Center with inputs from Ministry of Agriculture, Uganda National Meteorological Authority, Ministry of Health, FAO, FEWS NET, Uganda Red Cross	Uganda Crop Monitor, GLAM, EWX, Weather Forecasts	Via District Extension Agents, rapid food security assessments, and OpenDataKit	UNIEWS Bulletin, Disaster Risk Financing
 Tanzania	Ministry of Agriculture-Food Security Division coordinated with Tanzania Meteorological Agency (TMA), Ministry of Trade, National Bureau of Statistics (NBS)	GLAM, EWX, Tanzania Crop Monitor System	Via District Extension Agents, Regional Officers	Tanzania National Food Security Bulletin
 Rwanda	Ministry of Agriculture and Animal Resources with Rwanda Meteorology	GLAM, EWX, Rwanda Crop Monitor System	Via District Extension Officers	Rwanda Crop Monitor Bulletin



Photo credit: Unsplash

# Appendix A.

## The GEOGLAM Crop Monitor for Early Warning (CM4EW)

Over 40 partners from around the world contribute to producing the Crop Monitor reports, including government ministries, space agencies, and NGOs. Throughout the month, the Crop Monitor coordination team gathers relevant information from satellite data and recent publications to be used in the Crop Monitor Report.

### Partner Submissions

In the last ten days of the month, partner organizations monitoring AMIS/EW countries submit crop conditions using the common crop condition classification system to the online interface based on their own data sources and decision support systems. In many cases, countries overlap in submissions where multiple agencies submit information on crop conditions.

For example, in East Africa, up to six agencies submit inputs to the interface on current crops status in a given month, including IGAD ICPAC and USAID FEWS NET in Nairobi, Kenya and as well as remotely from FAO GIEWS and the UN WFP in Rome, Italy, and the EC Joint Research Centre (EC JRC) in Ispra, Italy, as well as others.

Submitted crop conditions are compared and reviewed, and discrepancies, where multiple organizations provide conflicting crop condition assessments for the same region, are compiled and sent out to partners for review.

### Datasets

- NDVI & NDVI anomalies from GLAM
- Evaporative Stress Index from the USDA NOAA
- Temperature anomalies from the EC JRC
- Precipitation anomalies from the University

of California, Santa Barbara CHIRPS and the EC JRC

- Evapotranspiration anomaly from the Land Data Assimilation System (FLDAS)
- Crop Masks and Crop Calendars

### Discrepancy Resolution

A teleconference is then held with all partners to provide an overview of crop conditions, discuss changes from the previous month, and resolve discrepancies between agencies.

Evidence in support of conditions is circulated and discussed until a consensus has been achieved amongst all partners.

### Product Development

Once a consensus on crop conditions is achieved, the draft text is written up, and graphics are developed based on agreed-upon conditions.

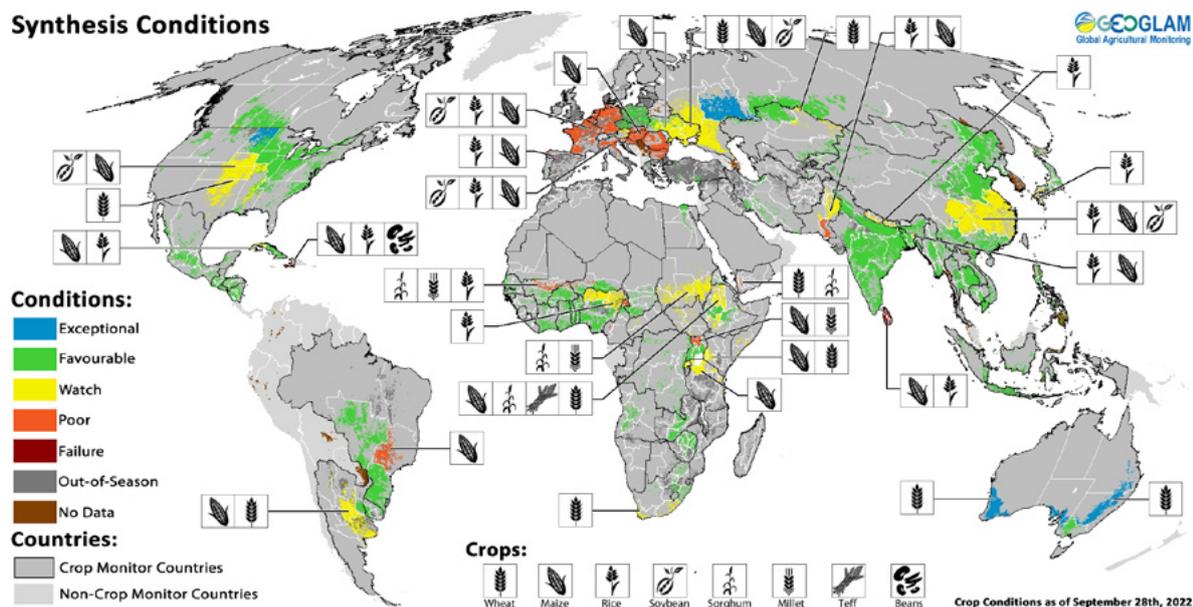
### Final Review and Publication

The draft text and graphics for each region are sent to the respective partner organizations for review and suggested edits are compiled into the final Crop Monitor reports that are published on the first Thursday of every month.

### Global Coverage

Combined with the Crop Monitor for AMIS and the CM4EW, the GEOGLAM Crop Monitor reports monthly consensus crop conditions for 93% of all global agricultural lands. These reports provide important updates to market and price communities as well as application to food security and early warning.

Figure 14 - Crop conditions for September 2022, as published in October 2022 report



## Appendix B.

# Common Indices for Agriculture Monitoring

Indices combine data to provide information relevant to understanding the state of crop conditions. When produced over long time spans, they can also be used to identify when current conditions are worse than historical averages. Many standard approaches to indices have been developed by integrating one or more essential variable(s). These can be leveraged by national monitoring systems as best practices.

Standard vegetation and water indices such as the Normalized Vegetation Difference Index (NDVI), Vegetation Health Index (VHI) and Vegetation Condition Index (VCI), Normalized Difference Water Index (NDWI), Water Satisfaction Index (WSI), Standard Precipitation Index (SPI) as well as the Soil Water Index (SWI) have long been used as proxies for measuring the state and health of crops. Definitions follow.

INDEX	DEFINITION
<b>NDVI</b>	Normalized Difference Vegetation Index is a ratio between the red (R) and near-infrared (NIR) values in the traditional fashion: $(NIR - R) / (NIR + R)$ , which is used to quantify vegetation greenness.
<b>EVI</b>	Enhanced Vegetation Index is a ratio between the R and NIR values (like NDVI), while reducing the background noise, atmospheric noise, and saturation in most cases.
<b>VCI</b>	Vegetation Condition Index compares the current NDVI to the range of values observed in the same period in previous years.
<b>NDWI</b>	The Normalized Difference Water Index is a ratio between the NIR and short-wave near-infrared (SWIR): $(NIR - SWIR) / (NIR + SWIR)$ , which reflects the moisture content in plants and soil.
<b>WSI</b>	Water Satisfaction Index is an indicator of crop (or rangeland) performance based on the availability of water to the crop during the growing season.
<b>SPI</b>	Standardized precipitation Index is used for estimating wet or dry conditions based on precipitation variables
<b>LST</b>	Land Surface Temperature is how hot the “surface” of the Earth would feel to the touch in a particular location.
<b>RFE</b>	Rainfall Estimates is the estimated precipitation

## Appendix C.

### Examples of Data Analytics Platforms (DAPs)

EXISTING APPLICATIONS	ESSENTIAL AGRICULTURE VARIABLES	DESCRIPTION
<a href="#"><u>ASAP</u></a>	<b>Crop condition, crop anomaly</b>	ASAP is a web-based decision support system for the early warning of hotspots of agricultural production anomalies (crop and rangeland) developed by the Joint Research Centre (JRC) of the European Commission for food security crisis prevention and response planning anticipation. ASAP can be used by countries for climate adaptation by identifying emerging areas of concern and triggering proactive response programs.
<a href="#"><u>GADAS</u></a>	<b>Crop condition, drought condition, Crop mask, Vegetation condition</b>	GADAS is a global, web-based agricultural assessment application used to monitor global agricultural conditions and assess the agricultural impact of natural disasters. GADAS is a powerful visualization tool based on an ArcGIS platform that enables Foreign Agriculture Service- International Production Assessment (FAS-IPAD) analysts and other users to assess real-time crop conditions rapidly.
<a href="#"><u>GIEWS</u></a>	<b>Crop/pasture condition, drought intensity</b>	GIEWS monitors the condition of major food crops across the globe to assess production prospects. To support the analysis and supplement ground-based information, GIEWS utilizes remote sensing data that can provide valuable insight into water availability and vegetation health during the cropping seasons.
<a href="#"><u>ASIS</u></a>	<b>Crop/pasture condition, drought intensity, Crop calendar, Phenology</b>	The Agricultural Stress Index System (ASIS) is a global agricultural drought information system developed and operated by FAO, Global Information and Early Warning System (GIEWS). ASIS simulates the analysis that remote sensing experts and agronomists would undertake and simplifies the usage and interpretation of the data for a broader audience of end-users to facilitate the early identification of cropland/grassland areas with a high likelihood of drought.
<a href="#"><u>WFP DataViz</u></a>	<b>Vegetation condition, drought intensity</b>	The VAM Data Visualization platform provides rainfall and seasonal vegetation profiles for monitoring agricultural seasons' performance. Users can assess rainfall and NDVI seasonal profiles (both current and long-term averages) and the progression of rainfall with monthly and three-monthly anomalies.
<a href="#"><u>GLAM</u></a>	<b>Crop condition, agricultural production</b>	GLAM is a global agricultural monitoring system that provides timely, easily accessible, scientifically validated, remotely sensed data, and derived products and doubles as a data analysis tool for crop condition monitoring and production assessment. GLAM enables inter-annual comparisons of seasonal dynamics and production of customized crop and pasture condition maps.
<a href="#"><u>CROPWATCH</u></a>	<b>Crop condition</b>	CROPWATCH provides analyses of global production and environmental and agricultural trends. In addition, CROPWATCH CLOUD provides an online cloud based analytical tools for national scale monitoring of crop conditions. Parameters include NDVI, fAPAR, LAI and cropping intensity.

## Appendix D.

# Summary of Common Data Sources for Agriculture Monitoring

DATASET SOURCE LINK	DESCRIPTION	DERIVED INFORMATION/ REFERENCE
<a href="#">MODIS - Vegetation Index Products</a>	MODIS vegetation indices, produced on 16-day intervals and at multiple spatial resolutions, provide consistent spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll and canopy structure. Two vegetation indices are derived from atmospherically corrected reflectance in the red, near-infrared, and blue wavebands; the normalized difference vegetation index (NDVI), which provides continuity with NOAA's AVHRR NDVI time series record for historical and climate applications, and the enhanced vegetation index (EVI), which minimizes canopy-soil variations and improves sensitivity over dense vegetation conditions. The two products more effectively characterize the global range of vegetation states and processes.	Vegetation indices
<a href="#">CHIPRS</a>	A 35+ year quasi-global rainfall data set. Spanning 50°S-50°N (and all longitudes) and ranging from 1981 to near-present, CHIRPS incorporates our in-house climatology, CHPclim, 0.05° resolution satellite imagery, and in situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring.	Precipitation <a href="#">Funk et al. 2015</a>
<a href="#">ECMWF</a>	The European Centre for Medium-Range Weather Forecast is one of the largest meteorological data archives and is responsible for producing global numerical weather predictions and other data for its stakeholders.	Multiple
<a href="#">FLDAS</a>	A custom instance of the NASA Land Information System ( <a href="#">LIS</a> ) that has been adapted to work with domains, data streams, and monitoring and forecast requirements associated with food security assessment in data-sparse, developing country settings. Leverages existing land surface models to generate ensembles of soil moisture, ET, and other variables based on multiple meteorological inputs or land surface models.	Multiple <a href="#">McNally et al. 2017</a>
<a href="#">SMAP</a>	The Soil Moisture Active Passive satellite mission measures surface soil conditions everywhere on Earth every two to three days, distinguishing between ground that is frozen or thawed. In ground that is not frozen or covered in water, SMAP measures how much water is in the top layer of soil, using this information to produce global maps of soil moisture.	Soil moisture
<a href="#">SMOS</a>	The Soil Moisture Active Passive satellite mission measures surface soil conditions everywhere on Earth every two to three days, distinguishing between ground that is frozen or thawed. In ground that is not frozen or covered in water, SMAP measures how much water is in the top layer of soil, using this information to produce global maps of soil moisture.	Soil moisture
<a href="#">ESI</a>	Evaporative Stress Index is global geospatial dataset that reveals regions of drought where vegetation is stressed due to lack of water, capturing early signals of drought without using observed rainfall data; this is critical in developing regions and other parts of the world lacking sufficient ground-based observations of rainfall. The ESI is based on satellite observations of land surface temperature, which are used to estimate water loss due to evapotranspiration (ET) – the loss of water via evaporation from soil and plant surfaces and via transpiration through plant leaves.	
<a href="#">CMORPH</a>	Global precipitation analyses are produced at a very high spatial and temporal resolution, delivering real-time products and information that predict and describe climate variations on timescales from weeks to years, thereby promoting effective management of climate risk and climate-resilient society. The CMORPH technique uses precipitation estimates that have been derived from low orbiter satellite microwave observations exclusively and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data.	Precipitation <a href="#">Joyce et al., 2004</a>

<b>DATASET SOURCE LINK</b>	<b>DESCRIPTION</b>	<b>DERIVED INFORMATION/ REFERENCE</b>
<a href="#">CPC</a>	The Climate Prediction Center collects and produces daily and monthly data, time series, and maps for various climate parameters, such as precipitation, temperature, snow cover, and degree days for the United States Pacific Islands, and other parts of the world. The CPC also compiles data on historical and current atmospheric and oceanic conditions, El Niño Southern Oscillations (ENSO) and other climate patterns such as the North Atlantic and Pacific Decadal Oscillations and stratospheric ozone and temperature.	Multiple
<a href="#">MODIS Landcover</a>	The MODIS Terra+Aqua Combined Land Cover product incorporates five different land cover classification schemes, derived through a supervised decision-tree classification method. The primary land cover scheme identifies 17 classes defined by the IGBP, including 11 natural vegetation classes, three human-altered classes, and three non-vegetated classes. The Land Cover Dynamics product includes layers on the timing of vegetation growth, maturity, and senescence that mark the seasonal cycles. Estimates of vegetation phenology are provided twice annually from the two 12-month focus periods, July-June, and January-December, allowing for hemispheric differences in the growing seasons, and enabling the product to capture two growth cycles if necessary.	Landcover
<a href="#">PROBA-V</a>	This is a miniaturized ESA satellite tasked with a full-scale mission to map land cover and vegetation growth across the entire planet every two days. This mission supports applications in land use, worldwide vegetation classification, crop monitoring, famine prediction, food security, disaster monitoring and biosphere studies. The vegetation instrument has the capacity to distinguish between land cover types, plant and crop species and health, water bodies and vegetation burn scars.	Landcover <a href="#">Dierckx, et al., 2014</a>
<a href="#">VIIRS NDVI</a>	This product build on the ~34-year multi-sensor VI record (AVHRR + MODIS + VIIRS) and continues this highly valuable and unique long term VI data record (NDVI, EVI, EVI2), and establishes a future and longer term outlook for VI climate data records and Earth System Data Records(continuity).	Normalized Difference Vegetation Index <a href="#">Didan et al., 2017</a>
<a href="#">SPOT NDVI</a>	The SPOT-VEG (Vegetation) sensor provides global coverage on an almost daily basis at a spatial resolution of 1 kilometer, with spectral bands designed specifically to study vegetation cover and temporal dynamics. The red and near-infrared bands are used to calculate maximum value NDVI composites every 10 days.	Normalized Difference Vegetation Index
<a href="#">GSOD</a>	Global summary of the day is comprised of a dozen daily averages computed from global hourly station data. Daily weather elements include mean values of: temperature, dew point temperature, sea level pressure, station pressure, visibility, and wind speed plus maximum and minimum temperature, maximum sustained wind speed and maximum gust, precipitation amount, snow depth, and weather indicators.	Multiple <a href="#">GSOD</a>
<a href="#">MERRA</a>	The Modern-Era Retrospective analysis for Research and Applications (MERRA) dataset was produced on a $0.5^\circ \times 0.66^\circ$ grid with 72 layers spanning the years 1972 - 2016 (Feb). The dataset was released in 2009 and has been used to drive stand-alone reanalyses of the land surface (MERRA-Land) and atmospheric aerosols (MERRAero).	Multiple <a href="#">Rienecker et al., 2011</a>
<a href="#">TRMM</a>	The Tropical Rainfall Measuring Mission is a daily accumulated precipitation product is generated from the research-quality $0.25^\circ \times 0.25^\circ$ , 3-hourly TRMM Multi-Satellite Precipitation Analysis TMPA (3B42). It is produced at the NASA GES DISC, as a value-added product. Simple summation of valid retrievals in a grid cell is applied for the data day. The result is given in (mm). This dataset is intended to provide the best estimate of 'quasi-global' precipitation from a wide variety of modern satellite-borne precipitation related sensors.	Precipitation
<a href="#">ERA Reanalysis</a>	ERA-Interim/Land is a global 6-hourly reanalysis of land-surface parameters from 1979-2010 at 80 km spatial resolution. The dataset is a result of a single 32-year simulation with the latest ECMWF land surface model driven by meteorological forcing from the ERA-Interim atmospheric reanalysis and precipitation adjustments based on Global Precipitation Climate Project.	Multiple <a href="#">Balsamo et al., 2015</a>

<b>DATASET SOURCE LINK</b>	<b>DESCRIPTION</b>	<b>DERIVED INFORMATION/ REFERENCE</b>
<a href="#"><u>NOAA-STAR Vegetation</u></a>	Vegetation Health Indices (VHI) derived from the radiance observed by the Advanced Very High-Resolution Radiometer (AVHRR) onboard afternoon polar-orbiting satellites. With a spatial resolution of 4km and a temporal resolution of 7 days, this dataset spans the period 1981 to present. The VH products can be used as proxy data for monitoring vegetation health, drought, soil saturation, moisture and thermal conditions, fire risk, greenness of vegetation cover, vegetation fraction, leave area index, start/end of the growing season, crop and pasture productivity, teleconnection with ENSO, desertification, mosquito-borne diseases, invasive species, ecological resources, land degradation, etc.	Vegetation indices
<a href="#"><u>COPERNICUS4 GEOGLAM</u></a>	The main objective of the new Copernicus4GEOGLAM component within the Global Land Service is to strengthen national and sub-national level agricultural monitoring systems in GEOGLAM partner countries, by making available the following ground validated crop monitoring baseline products, based on data from the Copernicus Sentinel-1 and 2 satellites: <ul style="list-style-type: none"> <li>• in-season and end of season crop type maps and crop masks;</li> <li>• in-season and end of season crop area statistics.</li> </ul>	Crop mapping and crop area statistics
<a href="#"><u>CGLS</u></a>	The Copernicus Global Land Service is a component of the Land Monitoring Core Service (LMCS) of Copernicus, the European flagship program on EO. The Global Land Service systematically produces a series of qualified bio-geophysical products on the status and evolution of the land surface, at global scale and at mid to low spatial resolution, complemented by the constitution of long-term time series. The products are used to monitor the vegetation, the water cycle, the energy budget and the terrestrial cryosphere.	Landcover
<a href="#"><u>C3S</u></a>	The Copernicus Climate Change Service supports society by providing authoritative information about the past, present and future climate in Europe and the rest of the World. The C3S mission is to support adaptation and mitigation policies by providing consistent and authoritative information about climate change. We offer free and open access to climate data and tools based on the best available science to inform policy development to protect citizens from climate-related hazards such as high-impact weather events; improve the planning of mitigation and adaptation practices for key human and societal activities; and promote the development of new services for the benefit of society.	Multiple
<a href="#"><u>GlobCover</u></a>	GlobCover is an ESA initiative which began in 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The aim of the project was to develop a service capable of delivering global composites and land cover maps using input observations from the 300m MERIS sensor on board the ENVISAT satellite mission. ESA makes available the land cover maps, which cover 2 periods: December 2004 - June 2006 and January - December 2009.	Landcover
<a href="#"><u>WorldCover</u></a>	ESA's WorldCover Project provides a new baseline global land cover product at 10 m resolution for 2020 based on Sentinel-1 and 2 data that was developed and validated in almost near real time and at the same time maximizes the impact and uptake for the end users.	Landcover
<a href="#"><u>CCI Landcover</u></a>	The purpose of the Land_Cover_CCI project is to make the best use of available satellite sensor data in order to provide an accurate land cover classification that can serve the climate modeling community.	Landcover
<a href="#"><u>Sentinel 1</u></a>	With the objectives of Land and Ocean monitoring, Sentinel-1 will be composed of two polar-orbiting satellites operating day and night, and will perform Radar imaging, enabling them to acquire imagery regardless of the weather. The first Sentinel-1 satellite was launched in April 2014.	Multiple

DATASET SOURCE LINK	DESCRIPTION	DERIVED INFORMATION/ REFERENCE
<a href="#">Sentinel 2</a>	The Copernicus Sentinel-2 mission comprises a constellation of two polar-orbiting satellites placed in the same sun-synchronous orbit, phased at 180° to each other. It aims at monitoring variability in land surface conditions, and its wide swath width (290 km) and high revisit time (10 days at the equator with one satellite, and 5 days with 2 satellites under cloud-free conditions which results in 2-3 days at mid-latitudes) will support monitoring of Earth's surface changes.	Multiple
<a href="#">Landsat Series</a>	Landsat shows us Earth from space. Since the first Landsat satellite launched in 1972, the mission has collected data on the forests, farms, urban areas and freshwater of our home planet, generating the longest continuous record of its kind. Decision makers from across the globe use freely available Landsat data to better understand environmental change, manage agricultural practices, allocate scarce water resources, respond to natural disasters and more. Specifically for Agriculture, the freely-available information is used to help identify the type and distribution of major crops across the globe, measure how agriculture is expanding or shrinking in remote regions, and monitor crop health and the condition of pastures and rangelands. This information is used to predict levels of food production, produce commodity forecasts, help farmers make planting decisions, and anticipate global or regional food shortages to aid in relief planning.	Multiple
<a href="#">WorldCereal*</a>	WorldCereal aims to develop an efficient, agile and robust EO based system for timely global crop monitoring at field scale. The OpenSource WorldCereal system will be able to: <ul style="list-style-type: none"> <li>• Create local to global annual cropland extent maps at 10 m resolution</li> <li>• Update the crop maps on a seasonal basis</li> <li>• Differentiate between actively irrigated and rainfed fields</li> <li>• Produce global maps of maize and wheat, two of the major staple crops</li> </ul>	Cropland maps

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