

CEOS STRATEGIC RESPONSE TO GEOGLAM REQUIREMENTS

Version 3.0 – October 2015



Table of Contents

Executive Summary	2
1 Introduction	4
1.1 Purpose of the Document.....	4
1.2 Scope.....	4
1.3 Contents	4
1.4 Revision History	5
1.5 CEOS Ad Hoc Working Group for GEOGLAM: Brief History and Objectives.....	5
2 GEOGLAM	7
2.1 Overview.....	7
2.2 Research and Development.....	8
2.3 Crop Monitor Activities	10
2.4 Asia-RiCE	11
3 Requirements	12
3.1 Target Product Specifications	12
3.2 Satellite Observation Requirements for Target Products.....	14
3.3 Archive Data	15
4 Acquisition Strategy	16
4.1 Basic Strategy for the GEOGLAM Development Phase	16
4.2 Data Streams	17
4.3 Individual Roles of the Data Streams	19
5 Next Steps	21

Executive Summary

The Group on Earth Observations (GEO) Global Agricultural Monitoring (GEOGLAM) initiative aims to support agricultural production estimates through the use of Earth observations. It was developed in response to the G20 Agricultural Ministers' concern about market volatility for the world's major crops. The initiative's goal is to strengthen the international community's capacity to produce and disseminate relevant, timely and accurate forecasts of agricultural production at national, regional and global scales through the use of Earth observations. GEOGLAM data outputs will directly support the Agricultural Market Information System (AMIS), a partner initiative launched by the G20 Agricultural Ministers and endorsed by the G20 heads of states. The R&D component of GEOGLAM has been operating since 2011, with support from the Committee on Earth Observation Satellites (CEOS).

The first version of this document was known as the CEOS Acquisition Strategy for GEOGLAM, and was endorsed with a phasing approach to echo the phases from the GEOGLAM Implementation Plan. Since then, it has been acknowledged that GEOGLAM currently employs what is referred to as a "community centric dynamic implementation" plan, which reflects the fact that GEOGLAM is an umbrella initiative, providing a common context and community of practice to support implementation of different projects, programs, and activities as they move at their own pace. In the long term, GEOGLAM aims to support the development of sustainable EO-based national agricultural monitoring systems, and as adoption of EO-based methodologies will be heterogeneous across different political and agricultural landscapes, it is necessary to view the implementation of GEOGLAM as user-driven and user-defined. As such, this CEOS Acquisition Strategy for GEOGLAM responds to evolving project-specific needs as a part of this "Development" phase.

The Strategy considers the satellite observations required as three data streams:

- **Core (expected to best meet the requirements, in most cases freely available):** MODIS (on Aqua and Terra), Landsat-7/8, Sentinel-2A, RADARSAT-2, Sentinel-1A, GCOM-W1, RapidEye, and GPM;
- **Contributing (used for evaluation in the event the primary data stream is not available or for extended research to evaluate complementarity with core datasets):** Suomi-NPP, Proba-V, SMOS, SPOT-5/6, Pleiades, Resourcesat-2, RISAT-1, ALOS-2, TerraSAR-X, COSMO-SkyMed; and
- **Future (to be assessed in future GEOGLAM phases):** SMAP, GCOM-C, Sentinel-2B, Sentinel-3A, RCM, VENUS, GCOM-W2, RISAT-1A, SPOT-7, and CBERS-4.

Data acquired from these missions will support the development of a range of target products. These products imply a wide range of spatial and temporal coverage by satellites, from monthly (for moderate resolution coverage such as Landsat) through daily (for MODIS, GPM, and GCOM-W). The Strategy defines acquisitions by relevant CEOS agency missions to support the target products and GEOGLAM Implementation Plan during 2015-2016. The strategy is:

- to address the minimum space data provision necessary for GEOGLAM pilot countries to engage in crop forecasting activities in 2015-2016;
- continue support to GEOGLAM research & development activities and application development under JECAM, SIGMA, and Asia-RiCE (a regional rice monitoring activity);

- to assess country-based space data archives for national agricultural forecast information systems;
- to respond to the current GEOGLAM data requirements, but also to anticipate GEOGLAM's future phases as well as the launch of additional satellites within the next few years which will improve CEOS capacity and the prospects for support; and
- to adapt to changes in requirements, and to space agency supply plans; further revisions and editions of the CEOS Acquisition Requirements for GEOGLAM should serve as the basis for on-going communication with, and coordination of, the CEOS agencies in support of GEOGLAM.

Noting the existing significant commitments of many of the same CEOS agencies and missions in support of GEO's Global Forest Observations Initiative (GFOI), the CEOS Strategic Response to GEOGLAM Requirements will be harmonised as far as possible with the equivalent CEOS strategy for GFOI, to ensure maximum efficiency in data acquisitions.

1 Introduction

1.1 Purpose of the Document

The purpose of this document is to explain how space agencies from the Committee on Earth Observing Satellites (CEOS) will coordinate their relevant Earth observing satellite systems to acquire data to support information requirements arising from the Group on Earth Observation's (GEO) Global Agricultural Monitoring initiative (GEOGLAM) for 2015-2016. The document has been prepared by the CEOS Ad-hoc Working Group on GEOGLAM and the primary audience is the CEOS community.

1.2 Scope

This document focuses on CEOS support for GEOGLAM in 2015-2016, and is the CEOS response to the GEOGLAM Implementation Plan (GEOGLAM IP, Spring 2015). GEOGLAM currently employs what is referred to as a "community centric dynamic implementation" plan, which reflects the fact that GEOGLAM is an umbrella initiative, providing a common context and community of practice to support implementation of different projects, programs, and activities as they move at their own pace. In the long term, GEOGLAM aims to support the development of sustainable EO-based national agricultural monitoring systems, and as adoption of EO-based methodologies will be heterogeneous across different political and agricultural landscapes, it is necessary to view the implementation of GEOGLAM as user-driven and user-defined. The Ad Hoc Working Group concluded that annual review of CEOS support to GEOGLAM, and annual updates to the Strategic Response are required because:

- The institutional framework for GEOGLAM evolves to respond to the agricultural monitoring community of practice's (AgCoP) needs and capacity. Confidence in a sustained future for the initiative can develop as capacity is seen to grow in the AgCoP, with CEOS seeing demonstrable capability to manage and utilize the significant volumes of space data being requested for acquisition;
- GEOGLAM is the second global initiative in recent years requiring significant satellite observations of the land surface (following GFOI, the Global Forest Observations Initiative) and CEOS and its agencies will need to develop a way forward that ensures efficiencies in the acquisition, processing and distribution of the data;
- Current capacity to support major land surface imaging acquisition programmes with freely available satellite data streams is limited to the Landsat series; but the launch of GCOM-W in May 2012, GPM in February 2014, Sentinel-1A (C-band SAR) in April 2014, ALOS-2 in May 2014, Sentinel-2A in July 2015, and a number of important missions anticipated to follow in the coming two years should support an expansion of ambitions for significant data acquisitions of the kind envisioned for a broader thematic and geographic implementation of GEOGLAM; and
- There is a need to develop, review, share and operationalize monitoring techniques and to validate the results in a stepwise fashion.

1.3 Contents

Section 2 provides more background on GEOGLAM and its precursor, the Joint Experiment for Crop Assessment and Monitoring (JECAM).

Section 3 defines the requirements communicated by GEOGLAM that determine the approach to a supporting space data acquisition strategy. It includes target product

specifications, satellite observation requirements for a future, fully-implemented GEOGLAM (i.e. all participating nations have the capacity for agricultural monitoring on a national scale), and temporal and spatial sampling needs.

Section 4 describes how CEOS agencies will **implement** the strategy and identifies the contribution of individual agencies and satellites.

1.4 Revision History

Version 1.0 of the document focused on CEOS support to GEOGLAM Phase 1 (2013-2015), and was endorsed by the 27th CEOS Plenary in Montreal, Canada, November 2013.

Version 2.0 of the document focused on the evolution of CEOS support to GEOGLAM for the period 2014-2015, and was endorsed by the 28th CEOS Plenary in Tromsø, Norway, October 2014.

Version 3.0 of the document focuses on the needs of GEOGLAM as it grows and evolves to respond to the AgCoP's needs and capacities, and highlights the crucial role CEOS has played in the development of the Initiative and best-practices/methodologies for monitoring via the JECAM, SIGMA (European Commission's Stimulating Innovation for the Global Monitoring of Agriculture), and Asia-RiCE (Asia Rice Crop Estimation & Monitoring) activities. **Additionally, for the first time, the CEOS Ad Hoc Working Group for GEOGLAM has developed a Scope of Work Document wherein the full depth and breadth of the WG's activities - which extend far beyond data acquisition to also tackle issues of strategic relationships, data access, availability, and usability - are covered.** For this reason, the current document has been streamlined to focus primarily on data acquisition.

1.5 CEOS Ad Hoc Working Group for GEOGLAM: Brief History and Objectives

The Committee on Earth Observation Satellites (CEOS) Ad Hoc Working Group for GEOGLAM was established in 2012 by CEOS to respond to the space-based Earth observation (EO) data needs set forth by GEOGLAM. Since 2013, the Ad Hoc Working Group has been preparing an annually updated strategy document, which included a statement of GEOGLAM data requirements, for CEOS Plenary's endorsement. The working group also focuses on fostering strategic relationships and promoting and facilitating data access, data availability, and data utilization, particularly in an agricultural monitoring context.

The group evaluates its progress annually, via conference calls, meetings, and the production of this strategic response document, with the following end goals in mind. Once these goals are met, the Ad Hoc Working Group can consider its mission accomplished:

- GEOGLAM is satisfied that most of its EO requirements are being and will continue to be met, recognizing the future will bring emerging needs and mission changes;
- GEOGLAM is satisfied it has valid global baseline datasets (e.g. crop area & type masks, and crop calendars) and can use CEOS-coordinated EO to make regular (3-5 years) updates.
- GEOGLAM is satisfied it has a plan for storing, processing, and analyzing space-based EO data through cloud-based or local solutions, and scene-based or data cube solutions.
- GEOGLAM is satisfied it has a baseline user agreement that will allow sharing of restricted data for R&D among many users and sites.

Post-ad hoc Working Group CEOS support to GEOGLAM will need to be defined by the Group before it is disbanded. The vision would be to account for the functions of the Group in existing CEOS entities such as the Land Surface Imaging Virtual Constellation (LSI-VC), the CEOS Systems Engineering Office (SEO), and others interested. Specific roles and responsibilities would need to be developed by the Working Group in cooperation and consultation with these other entities, but could include:

- evaluation of new EO requirements and missions, communicate availability of new EO datasets, and facilitate access to datasets by the LSI-VC; and
- maintaining of open source tools to support data management including the provision for Data Cubes, and supporting systems analyses by the CEOS SEO.

As of CEOS Plenary 2015, the nominal timeframe foreseen for such a transition would be 2-3 years, with many details remaining to be coordinated.

2 GEOGLAM

2.1 Overview

GEOGLAM aims to enhance agricultural production estimations and forecasts through the use of Earth observations, in order to address concerns about market volatility for the world's major crops, as raised by the G20 Agricultural Ministers. Mandated in 2011, it hopes to strengthen the international community's capacity to produce and disseminate relevant, timely, and accurate projections of crop and livestock production at national, regional, and global scales through the use of Earth observations. In the GEOGLAM context, both croplands and rangelands (grazing lands or pasturelands) fall under the purview of agriculture. Presently, the monitoring of croplands is the dominant focus, both thematically and geographically, as the rangeland monitoring activity (Rangeland and Pasture Productivity, RAPP) is in the process of developing its scope and community of practice.

The GEOGLAM Implementation Plan outlines six components that make up GEOGLAM:

- 1) Enhancing **regional to global** agricultural production monitoring systems;
- 2) Supporting **national monitoring systems** ;
- 3) Supporting **monitoring of countries at risk** to improve food security;
- 4) Improving **coordination of Earth observations** (EO; data acquisition and dissemination) for agricultural monitoring;
- 5) Coordinating **research and development toward operations** in support of improved operational agricultural monitoring; and
- 6) **Developing capacity** for utilizing EO, at multiple levels and scales.

This Plan calls for CEOS to contribute to Components 1, 4, and 5 of the GEOGLAM Work Plan.

Component 1 - coordinating space data support for the Asia-RiCE countries (see Section 2.4 and 2.5).

Component 4 - coordination, as the space arm of GEO, and increased use of Earth observations to improve operational agricultural monitoring. The full scope of this activity, which includes the activities of the CEOS Ad Hoc Working Group for GEOGLAM, can be found in the accompanying "Scope of Work" Document referenced in Section 1.4.

Component 5 - coordinating continuing support to GEOGLAM R&D efforts through JECAM and SIGMA (see Section 2.2).

2.1.1 GEOGLAM Advisory Committee

In February 2013, it was established that GEOGLAM's administrative structure should include a Secretariat Program Office, an Implementation Team, and an Advisory Committee. In November 2015, during GEO Plenary XII (Mexico City, the week after CEOS Plenary), GEOGLAM will convene its first Advisory Committee with staffing of high-level personnel from different countries, NGOs, and international organizations (e.g. CEOS, UN FAO). The Advisory Committee is largely staffed from the "demand-side" with users of space-based observations and EO-based information on agriculture, to encourage national and international institutional support for the development of national monitoring systems. However, recognizing the importance of the "supply-side" to the successful implementation of GEOGLAM, there is also representation from funding agencies and from CEOS (in the form of the CEOS Chair). Insight from the Advisory Committee will help guide the future directions of GEOGLAM, and their advice and guidance will influence future iterations of the GEOGLAM Implementation Plan as well as this strategic response document.

2.2 Research and Development

JECAM provides the foundation for the research and development towards operational monitoring enhancements for GEOGLAM. Since late 2013, the European Commission's SIGMA initiative has added to the research and development activities of GEOGLAM, with many sites being added to the JECAM network. CEOS has been providing support to Component 5 of the GEOGLAM Work Plan through JECAM since 2011. The EO data that was provided to the JECAM can be found in their annual report at the JECAM website. Further, while Asia-RiCE formally falls under Component 1, as a regional monitoring system, a great deal of R&D activities are taking place at a variety of technical demonstration sites, with CEOS coordinating crucial space assets for these areas as well. This activity and CEOS contributions are covered in Section 2.4.

The overarching purpose of JECAM is to compare data and methods for crop area, crop condition monitoring and yield estimation, with the aim of establishing 'best practices' for different agricultural systems. The goal of the JECAM experiments is to facilitate the inter-comparison of monitoring and modelling methods, product accuracy assessments, data fusion, and product integration for agricultural monitoring. These international shared experiments are being undertaken at a series of sites which represent many of the world's main cropping systems. The approach is to collect and share science and data, including: i) time-series datasets from a variety of Earth observing satellites useful for agricultural monitoring, and ii) in-situ crop and meteorological measurements for each site. Additional information is available from the JECAM website (JECAM.org).

Synthesis of the results from JECAM will enable the following outcomes:

- Development of international standards for agricultural monitoring and reporting protocols;
- A convergence of the approaches to define best monitoring practices for different agricultural systems; and
- Identification of requirements for future EO systems for agricultural monitoring.

The JECAM sites are looking at a common range of monitoring needs over a very diverse range of landscape conditions and cropping systems, including:

- Crop identification and acreage estimation;
- Yield prediction;
- Near Real Time Crop condition / Crop stress;
- Land management; and
- Soil moisture.

There are currently 35 JECAM sites. Some of these are very active, while others are dormant. There is already significant bi-lateral collaboration between JECAM sites planned and underway. Use of the site network to support research external to JECAM is already taking place.

In July 2014, an international JECAM Science Meeting was held in Ottawa, Canada. At this time, two documents were proposed as new JECAM standards: Minimum EO Data Sets, and Guidelines for Field Data Collection. Consensus was achieved on certain key points, but the agreement of standards is ongoing. There was also consensus on key research topics, namely:

- What are the different performing features/metrics to discriminate the cropland/crop type for the different agricultural landscapes (including smallholders' agriculture)?

- What are the limitations to extend the currently operational SAR method for crop mapping, soil moisture and biophysical variables?
- How to develop multisource approaches (sensor independent methods)?
- How to scale up from finer to coarser resolution?
- What are the stratification approaches to move from site level to regional/national level?
- How to detect/focus on change from one year to another (crop type, crop yield, cropland)?
- What are the yield models to be developed in data rich environment?
- How to input crowd sourcing and expert knowledge into an EO-driven system?
- How to detect water stress (indicators, etc) including thermal IR?

The JECAM network plans to continue to address these key topics and feed the results to GEOGLAM.

At the centre of many discussions that have occurred over the past year is the need for justification for sharing CEOS-coordinated data between and across JECAM sites and participants. As the goal of JECAM is to derive best practices for agricultural monitoring, and to develop methodologies that are generalizable between diverse agricultural landscapes, it is crucial that data be available to JECAM site participants worldwide regardless of whether a given participant's principal involvement is with only one specific region. Moving forward, it is an important activity of the CEOS Ad Hoc Team for GEOGLAM to clearly communicate this scientific need to involved space agencies.

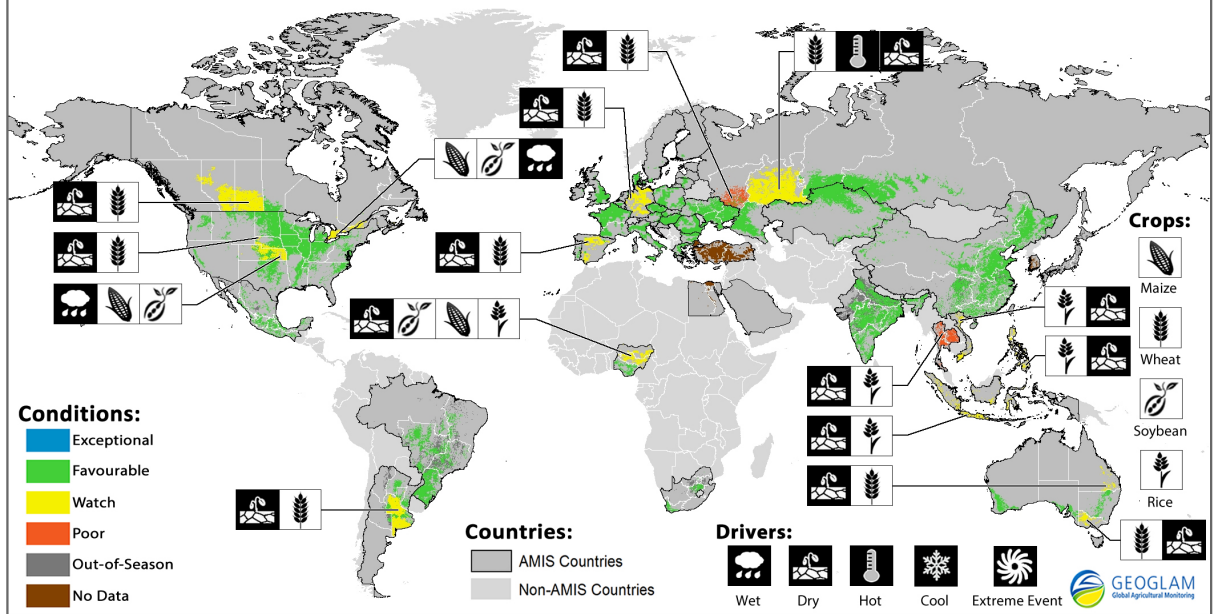
In an effort to expand the use of satellite data for JECAM and to enhance sharing of analysis methods across test sites, the CEOS SEO is developing a Space Data Management System (SDMS) to be hosted in a cloud-computing environment. This system will be completed in late-2015 and will focus on SAR intercomparison studies across several test sites.

In addition, the SEO has been working closely with CSA and MDA to develop a Multi-User Request Form (MURF) that provides access to Radarsat-2 data for JECAM purposes, across multiple JECAM sites. This user agreement is a broad agreement serving more than individual users, but the larger JECAM project. It is expected that this process will set a precedent for future data sharing arrangements to support GEOGLAM and other CEOS initiatives.

Requirements for JECAM, while continuing to be supported by ongoing CEOS activities, were not explicitly addressed in the CEOS Acquisition Strategy for GEOGLAM Phase 1, nor are they explicitly addressed herein. It is expected that in subsequent years, as the methodologies mature, the JECAM data requirements may in fact grow together, or be blended or further harmonized with the mainline GEOGLAM requirements.

2.3 Crop Monitor Activities

The GEOGLAM Implementation Plan calls for direct support to the AMIS, a partner initiative launched by the G20 Agricultural Ministers and endorsed by the G20 head of states and a key beneficiary of the GEOGLAM outputs. Since September 2013, GEOGLAM has operationally provided monthly crop outlook reports known as the AMIS Crop Monitor



(ACM) to AMIS as inputs to their Market Monitor.

Figure 1 Crop condition map synthesizing information for all four AMIS crops as of July 28th, 2015. Crop conditions over the main growing areas for wheat, maize, rice, and soybean are based on a combination of national and regional crop analyst inputs along with earth observation data. Crops that are in less than favourable conditions are displayed on the map with their crop symbol.

These products focus on the conditions of wheat, soybean, maize, and rice in the G20+7+Spain countries. They are derived from a number of space-based and *in situ* observations, including satellite data contributions from CEOS agencies. Many points of information are utilized, including NDVI & NDVI anomaly and satellite derived agrometeorological information such as NDVI anomaly, water stress, soil moisture, land surface temperature, drought index, PAR, and accumulated rainfall. Output products typically include synthesis maps which describe both the condition of the crops under cultivation, as well as the drivers of that condition, and pie charts indicating crop conditions for main producer and main exporter countries.

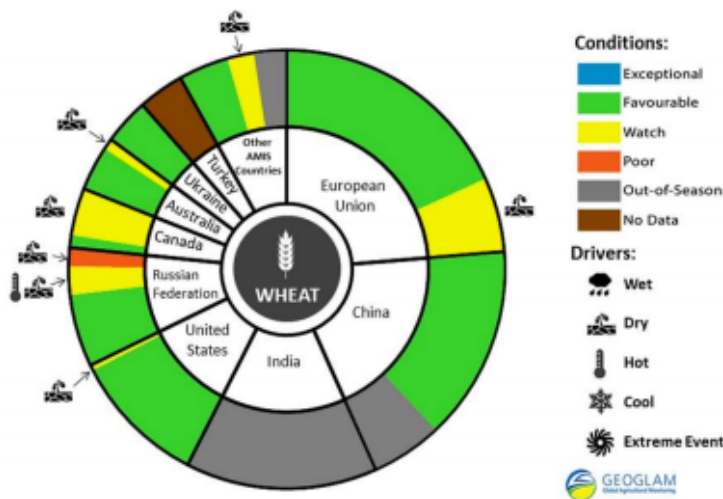


Figure 2 Example pie chart showing global wheat conditions as of 28th of June, 2015.

In early 2013, the ACM was only one page in length, and many AMIS economists found the inclusion of spatial data unnecessary or confusing; it is a testament to the value of the ACM and the people who make it happen that GEOGLAM's ACM now has three full pages in the AMIS Market Monitor. In fact, in the first year review of the AMIS Market Monitor, GEOGLAM's ACM was voted by users as one of the most valuable portions of the publication. In May 2015, AMIS decided to formalize its relationship with GEOGLAM, further solidifying the value of EO-based analyses in general, and particularly that of GEOGLAM's unique placement to develop international consensus on crop conditions.

Building on this experience and success, GEOGLAM is currently developing an Early Warning Crop Monitor (EWCM) with leadership from the Joint Research Centre (JRC), and USGS/FEWSNET, and the World Food Programme (WFP). This EWCM will focus on countries-at-risk for food insecurity, and will report on the conditions of regionally-relevant crops and regionally-relevant drivers of sub-favourable crop conditions.

2.4 Asia-RiCE

A group for the coordination of observations for Asian rice crops known as Asia-RiCE (Asian Rice Crop Estimation, Monitoring, and Outlook) was created under the leadership of JAXA and ISRO in support of GEOGLAM. The Asia-RiCE initiative has been organised to develop the rice crop monitoring component of the GEOGLAM initiative. This group has been focused on defining observational requirements, working with a number of Asian countries to define Technical Demonstration sites in 2013-2015. These sites are described in Asia-RiCE Implementation Plan (<http://asia-rice.org/>), and coordination has been on going to refine the data requirements for these sites - in particular for SAR. The Asia-RiCE team has also focused on supporting the Demonstration sites in securing the required flow of data, and analysing this data along with ground based information and the models to estimate paddy field planting area, rice crop growth and production, and generate other related products. The Asia-RiCE team has also responded to Announcements of Opportunity from a number of CEOS agencies such as CSA (SOAR-JECM), DLR (TerraSAR/TanDEM-X), and JAXA (Kyoto and Carbon Phase 4) to promote research into the utilisation of multiple SAR data types (L-/X-/C-bands) by the Demonstration sites. The team has also coordinated with ISRO for access to RISAT data, with ESA for Sentinel-1 and -2 early acquisition planning, and with CNES for Venus acquisitions.

In addition with rice crop area and production estimation, Asia-RiCE contributes rice crop outlook to the GEOGLAM crop monitoring system using JAXA's agro-meteorological

information system (JASMIN) and other information sources and knowledge, and in cooperation with ASEAN+3 food security information system (AFSIS) projects and national experts. 15-day composites of NDVI, land surface temperature, PAR, soil moisture and drought index (KBDI) that are produced from MODIS, TRMM/GPM, GCOM-W, MTSAT and other satellites. The anomaly information for these 15-day composites, generated relative to climate information, is provided to AFSIS and national experts by JASMIN.

The SEO delivered a Space Data Management System (SDMS) to the Asia-RiCE team in 2015. This system allows cloud-based storage and processing of space datasets to support research. Many lessons were learned during this development, as the SEO has moved the location of the cloud server from the U.S, to Japan, and most recently to Singapore. These moves have improved computing performance. The Asia-RiCE team continues to test the system and provide feedback to the SEO.

3 Requirements

3.1 Target Product Specifications

The GEOGLAM Task Team has defined a number of thematic crop information product specifications including multi-annual, annual, near real-time/weekly products. These products serve as inputs to crop information systems such as the AMIS. A number of these products are to be produced in-season, and therefore near real time data distribution is required. A note on latency appears in Section 3.3.

Note that the requirement numbers referenced below are linked to Table 2 in Section 3.2.

Cropland Mask: A generalized map of cultivated areas, to be updated every 1-3 years, at Landsat scale. Finer resolution (requirements #7 - #11) may be required for smaller at-risk countries. This product requires monthly observations of cropland extent and regional Rice crop samples to enable differentiation between croplands and non-cropped lands. Monthly cloud-free Landsat scenes (minimum 2 out of season, 3 in season) are needed (requirements #4 and #5) at least every 3 years, ideally annually. In persistently cloudy areas, there will be a need to integrate additional optical and/or radar data. For example, Asia-RICE regions will utilise MODIS-class imagery (requirement #2), and will also investigate the utility of SAR imagery (requirement #6) to produce yearly cultivated rice area.

Crop Type Area and Crop Calendar: Annual derived cropland area estimates and crop calendars based on monthly observations over cropland extent (requirement #4), and weekly observations over cropland samples (requirement #5). In South-East Asia, there can be up to 3 rice crops in a year. For Asia-RiCE regions, MODIS-class (requirement #2) will be used, with monthly observations using SAR (requirement #6) having started being investigated end 2013. Observations should be optimized for periods where crop types can be differentiated from each other. Overall, there is a need for 4 to 6 cloud-free observations during the growing season of one crop cycle (i.e., Argentina has 2 soy crops within the same year so additional observations are needed). In addition to Landsat data, fine resolution data (e.g RapidEye) are needed monthly (requirements #7 - #11) in order to calibrate the Landsat derived area estimates.

Crop Condition: The health and growing condition of croplands based on coarse resolution data (e.g. MODIS, SAR, or passive microwave) for the detection of disease, flooding or droughts. Daily (requirement #1) to near-daily (requirement #2) observations will yield parameters including NDVI, LAI, FPAR, VHI, TCI, ET, precipitation, LST and Soil Moisture (passive microwave, requirement #3). Multi-year time series fine resolution (requirement #8) and moderate resolution (requirements #5 and #6) are used to define the normal growing

season to allow anomaly comparisons. In addition, this product requires integration with ground observations (e.g. crop production statistics).

Crop Yield: Derived cropland output (yield) is based on empirical information and crop growth information (e.g. NDVI, LAI, FAPAR, LST) from near-daily coarse resolution observations (requirement #2) and microwave measurements of precipitation, temperature and ET (requirement #3). While still in the research phase, in future biomass estimation using SAR will be considered. In addition, this product requires integration with ground observations (i.e., crop production statistics).

Crop Biophysical Variables: Crop variables (e.g. LAI, NPP, Nitrogen content, Chlorophyll content, Water content) from various resolution observations (requirements #1 - #3, #5, #6, and #8). In addition, this product requires integration with ground observations for calibration and validation.

Environmental Variables: Environment variables (e.g. soil type, soil moisture) from passive microwave, and moderate and fine resolution observations (requirements #3, #5, #6, and #8).

Agricultural Practices / Cropping Systems: Derived cropland products (i.e., field size, number of cropping cycles per season, diversity of crops) from all types of observations (i.e. coarse, moderate, fine and very fine) resolution observations (requirements #2, #4 - #6, #8, #10, and #11).

3.2 Satellite Observation Requirements for Target Products

Table 2 summarises the satellite observations required to support the generation of the target products defined in Section 3.1. This includes the required spatial resolution, spectral range, effective observation frequency, and sample type for each product. 11 requirements have been defined in support of the target products.

Req#	How ?		When ?	Where ?		What ? Information Products and Applications						
	Spatial Resolution	Spectral Range	Effective observ. frequency (cloud free)*	Sample Type	Field Size	Crop Mask	Crop Type Area and Growing Calendar	Crop Condition	Crop Yield	Crop Biophysical Variables	Environ. Variables	Ag Practices / Cropping Systems
Coarse Resolution Sampling (>100m)												
1	>500-2000 m	optical	Daily	Wall-to-Wall	All			X		L		
2	100-500 m	optical	2 to 5 per week	Cropland Extent	All	X	X	X	L	L	X	L
3	5-50 km	microwave	Daily	Cropland Extent	All			X	X	X	X	
Moderate Resolution Sampling (10 to 100m)												
4	10-70m	optical	Monthly (min 2 out of season + 3 in season). Required every 1-3 years.	Cropland Extent	All	X	L/M					X
5	10-70m	optical	~Weekly (8 days; min. 1 per 16 days)	Sample	All	X	X	X	X	X	X	X
6	10-100m	SAR Dual Polarization	~Weekly (8 days; min. 1 per 16 days)	Cropland Extent or Sample	All	X	X	X	X	X	X	X
Fine Resolution Sampling (5 to 10m)												
7	5-10 m	VIS, NIR, SWIR	Monthly (min. 3 in season)	Cropland Extent	M/S	M/S	M/S					
8	5-10 m	VIS, NIR, SWIR	~Weekly (8 days; min. 1 per 16 days)	Sample	All		M/S	X		X	X	X
9	5-10 m	SAR Dual Polarization	Monthly	Cropland Extent or Sample	M/S	M/S	M/S					M/S
Very Fine Resolution Sampling (<5m)												
10	< 5 m	VIS, NIR	3 per year (2 in season + 1 out of season); Required every 3 years	Cropland Extent	S	S	S					
11	< 5 m	VIS, NIR	1 to 2 per month	Refined Sample	All		X		X			X

Table 1 GEOGLAM Phase 1 Satellite Observational Requirements for Target Products

Field size variation: small (S ~ <2.5 ha), medium (M = ~2.5 ha-15 ha), and large (L = ~ >15ha)

* Cloud free < 10% average cloud cover across the scene.

Additional notes on Table 2:

- 'X' indicates data required for all field sizes; if data are to be used for only (or a combination of) large, medium, and/or small fields, the 'X' is supplanted with the field size designation.
- Optical data refers to data spanning the visible, near-infrared, shortwave infrared, and long-wave infrared (thermal). Data requirements spanning less or different portions of the spectrum are specified accordingly.
- Data should be made available near-real time, particularly for within season assessments;
- Requirements have maximum and minimum ranges for spatial resolution, temporal resolution, and in some cases geographic extent;
- Spatial resolution requirements are generated relative to field size; this is preliminary and could be refined/improved with a consideration of landscape heterogeneity and spatial pattern;
- Meteorological parameters (snow cover, temp., rainfall, etc.) are not included in this table and will be addressed in another forum; and
- Samples need to be coordinated and nested, but at present have been developed largely in the context of specific project needs and considerations.

In order to try and ease the requirement on cropland extent coverage for fine and moderate resolution data streams, a sampling strategy (described in Section 3.4) has been proposed. This sampling strategy means that requirement #4 calls for coverage a minimum of every 1-3 years. While the sampling strategy is expected to be able to mitigate coverage gaps, the derived products are a less accurate estimate. Annual coverage of requirement #4 will optimise the quality of the end products, and is therefore desired.

3.3 Archive Data

There is a need for – as well as interest in and research capacity available for – the development of baseline datasets on a global basis, most notably crop type and crop calendars for the major crops (wheat, rice, maize/corn, and soybean). As GEOGLAM has evolved and grown, it has relied on “best-available” products for both its acquisition strategy development as well as for some of its cropland monitoring applications. Broadly speaking, these products have been derived through the intercomparison of existing products (cropland area mask), auxiliary or crowd-sourced data (field size data distribution layer), or analysis of continuous (time series) historical coarse spatial resolution data (growing season calendars and cloud cover analyses). The accuracy of these baseline products could all be improved through the incorporation of fine-to-moderate spatial resolution data (<100m, approximately), improving cropland monitoring activities as well as ensuring a more finely-tuned acquisition strategy moving forward.

These baseline products can be generated through the incorporation of archival data from a suite of fine-to-moderate spatial resolution active microwave (SAR) and passive optical sensors, including the Landsat, ALOS, Radarsat, Terrasar-X, ResourceSat, RapidEye, SPOT and RISAT missions.

This can be realized through a few incremental steps, each with additional benefits which advance us toward an operational monitoring program:

1. CEOS SEO incorporates acquisition metadata from these missions into COVE.
 - a. Benefits: Establishes a pipeline of these metadata, which will be valuable moving forward for many CEOS activities; generates a database which GEOGLAM can evaluate for sufficient data sampling rate for target product activity.

2. COVE analysis run to identify data granules acquired over croplands (defined by current best-available cropland mask), within growing season (defined by current best-available growing season calendars); GEOGLAM identifies which data granules comprise a sufficient record to develop crop type and crop calendar products.
 - a. Benefits: Provides a basis for evaluation of new data streams; generates baseline products which will make future data acquisitions (when & where) more precise.
3. CEOS requests data granules from respective space agencies.
 - a. Benefits: Establishes a process by which data are requested by GEOGLAM, with CEOS coordinating through space agencies; takes advantage of already acquired data, rather than new acquisitions.
4. Data placed in one (or more) of the data services prototypes.
 - a. Benefits: Provides an opportunity to test the data services prototypes.

Providing the archive contains data of sufficient quantity and availability for their production, these data products would become the new standard for GEOGLAM activities. As agriculture is a dynamic process both within and between years, the products would require updating every 1-3 years, thereby in the future relying on near-real time acquisitions. The specific frequency of updating of the baseline products (including crop mask, crop type, and crop calendar) can be found in the requirements table (Table 2).

4 Acquisition Strategy

4.1 Basic Strategy for the GEOGLAM Development Phase

The CEOS Acquisition Strategy for GEOGLAM may be characterised as:

- aiming to address the minimum space data provision necessary for GEOGLAM countries to engage in crop projection activities;
- based on acquisitions from a number of data streams – as agency data policy allows, provide access to the resulting data archives by countries for national agricultural forecast information systems;
- responding to the current GEOGLAM Implementation Plan, but anticipating future phases, and the launch of additional satellites within the next few years which will improve CEOS capacity and the prospects for support to future GEOGLAM phases; and
- adaptive to changes in requirements, and to space agency supply plans; further revisions and editions of the CEOS Acquisition Strategy should serve as the basis for on-going communication with, and coordination of, the CEOS agencies in support of GEOGLAM.

The Strategy focuses on activities consistent with the objectives of supporting the development of GEOGLAM, while also allowing the opportunity to assess GEOGLAM development and evolving data requirements before defining and committing to potential CEOS support for future phases.

The geographic extent of pilot countries support is limited to the countries listed in Table 1 in order to ensure the coverage area (approximately 1.3 million km²) remains manageable. This acknowledges the need for GEOGLAM to demonstrate activities at scale, while also recognising that it is still in its formative stages, and does not yet have the capacity to support a global program.

The Strategy identifies Core and Contributing data streams to support implementation, with the aim of communicating the prospective roles of the data providers. These data streams are

characterised by their data access policy, maturity and availability, and their fitness to support the generation of the target products specified by the GEOGLAM Task Team.

4.2 Data Streams

Discussions between CEOS agencies active within the JECAM task, and the GEOGLAM Task Team have resulted in consensus on a working list of CEOS agency satellite missions that represent the candidate GEOGLAM data streams. These data streams fall into one of two categories: Core and Contributing.

Core data streams are the current source of data that are expected to best meet the requirements. In most cases these data are freely available, but in some cases (e.g. RapidEye) these datasets may require a fee or special negotiation with an agency or commercial partner. GEOGLAM would like to pursue free and open access to all Core datasets for its development phases with the intention of securing funding for these data for long-term operational use should needs warrant.

Contributing data streams are the source of data that would be used for evaluation in the event the Core data streams are not available. It is possible that evaluation of Contributing data will result in improved results such that a Contributing data source may be considered as a Core dataset in the future. GEOGLAM would like to pursue free and open access to all Contributing datasets for its development phases with the intention of securing funding for these data for long-term operational use should needs warrant.

Table 4 shows how the GEOGLAM Core and Contributing data streams relate to the target product requirements defined in Section 3.2.

	How ?				Where ?	When ?	
Req#	Core Missions (future)	Contributing Missions (future)	Spatial Resolution	Spectral Range	Sample Type	Effective observ. frequency (cloud free)*	Growing Season Calendar
Coarse Resolution Sampling (>100m)							
1	Aqua/Terra (1000m)	Suomi-NPP (750m) Proba-V (1000m) SPOT-5 (1150m)	>500-2000 m	optical	Wall-to-Wall	Daily	all year
2	Aqua/Terra (250/500m) Sentinel-3A (500m)	Suomi-NPP (375m) Proba-V (100/333m)	100-500 m	optical	Cropland Extent	2 to 5 per week	all year
3	Aqua GCOM-W1/W2	SMOS SMAP	5-50 km	microwave	Cropland Extent	Daily	all year
Moderate Resolution Sampling (10 to 100m)							
4	Landsat 7/8 (30m) Sentinel-2A/2B (10-20m)	ResourceSat-2 (56m) CBERS-4 (20-40m)	10-70m	optical	Cropland Extent	Monthly (min 2 out of season + 3 in season). Required every 1-3 years.	all year
5	Landsat 7/8 (30m) Sentinel-2A/2B (10-20m)	ResourceSat-2 (56m) CBERS-4 (20-40m)	10-70m	optical	Sample	~Weekly (8 days; min. 1 per 16 days)	growing season
6	Sentinel-1A/1B (C) Radarsat-2 (C), RCM (C) ALOS-2 (L)	RISAT-1/1A (C) RISAT-3 (L)	10-100m	SAR Dual Polarization	Cropland Extent or Sample	~Weekly (8 days; min. 1 per 16 days)	growing season
Fine Resolution Sampling (5 to 10m)							
7	RapidEye	SPOT-5/6, SPOT-7 CBERS-4	5-10 m	VIS, NIR, SWIR	Cropland Extent	Monthly (min. 3 in season)	growing season
8	RapidEye	SPOT-5/6, SPOT-7 CBERS-4	5-10 m	VIS, NIR, SWIR	Sample	~Weekly (8 days; min. 1 per 16 days)	growing season
9	Sentinel-1A/1B (C) Radarsat-2 (C), RCM (C) ALOS-2 (L)	RISAT-1/1A (C) RISAT-3 (L)	5-10 m	SAR Dual Polarization	Cropland Extent or Sample	Monthly	growing season
Very Fine Resolution Sampling (<5m)							
10		Pleiades, SPOT-6, SPOT-7	< 5 m	VIS, NIR	Cropland Extent	3 per year (2 in season + 1 out of season); Required every 3 years	all year
11		Pleiades, SPOT-6, SPOT-7	< 5 m	VIS, NIR	Refined Sample	1 to 2 per month	growing season

Table 2 GEOGLAM Phase 1 Target Product Observational Requirements Core and Contributing Data Streams

A summary of all data streams relevant to the GEOGLAM data strategy, including a summary of data policies and measurement capabilities, can be found in Appendix B.

4.3 Individual Roles of the Data Streams

The requirements outlined in Section 3.2 can be addressed by a combination of data streams from four basic instrument classes: coarse, moderate, fine and very fine resolution data streams.

Coarse Resolution: > 100m

MODIS will be the main workhorse for coarse resolution optical, thermal IR, and SWIR during GEOGLAM Phase 1. There are known continuity concerns, with **Terra and Aqua** operating well past their end of design life (expected >2020), and so contributing continuity options such as **Suomi-NPP**, and **VEGETATION** on **SPOT-5** and **Proba-V** will also be evaluated. The future Sentinel-3A mission will be considered after 2015.

TRMM, Aqua, GPM and GCOM-W1 will provide the required microwave data stream for precipitation data with GCOM-W2 as a future continuity option. TRMM, Aqua and GCOM-W1 will provide the required microwave datastream for soil moisture with **SMOS** as a contributing option, and **SMAP** and GCOM-W2 as potential future options.

MODIS (Terra and Aqua) <i>Requirements #1 and #2</i>	Standard products utilised at a daily frequency over the cropland extent to provide optical, thermal IR, and SWIR data streams.
GCOM-W <i>Requirement #3</i>	Utilised at a daily frequency over the cropland extent to provide a microwave data stream.
Contributing	Suomi-NPP, SPOT-5, Proba-V, SMOS (microwave)
Future	Sentinel-3A, SMAP (microwave)

Table 3 GEOGLAM Phase 1 Coarse Resolution (>100m) Data Streams

Moderate Resolution: 10 to 100m

It is expected that **Landsat** and **Sentinel-2** satellites will be the optical workhorses of GEOGLAM, providing moderate resolution coverage on a global scale. **RESOURCESAT-2** represents a contributing optical source which could be evaluated if the data are consistently available over the test sites. The requirement for annual crop extent optical data is potentially reduced by plans to employ a sampling strategy, described in Section 3.4.

RADARSAT-2 and **Sentinel-1A** (launched April 2014) will be the radar (C-band) workhorses for early GEOGLAM phases, providing coverage of the Asia-RiCE Technical Demonstration sites. It is also expected that **RISAT-1** (C-band) will make a contribution to Asia-RiCE monitoring, and will also be evaluated. As GEOGLAM moves towards operations, it is expected that radar data will be required for rice crop monitoring, with **Sentinel-1** expected to contribute a significant portion of the required C-band data. **ALOS-2** is a potential L-band data stream which will be evaluated once it becomes available (launched in May 2014, but still under checkout, with data policy to be confirmed). **COSMO-SkyMed** and **TerraSAR-X** data is being used by JECAM for X-band evaluations. Finally, limited coverage **CBERS-4** data will be evaluated in the future.

Landsat-7 and Landast-8 Requirements #4 and #5	Landsat will be used over cropland extent for 2-3 in season, and 2-3 out of season acquisitions, repeated at a minimum every 1-3 years, annually optimal. Research carried out in the context of the Ad Hoc Working Group has found that for many cropped areas, the two Landsat missions alone are insufficient to overcome persistent and pervasive cloud occultation of cropped land surfaces. For this reason, Sentinel-2A/B data will be crucial toward meeting GEOGLAM requirements (Whitcraft, Killough, et al., 2015, <i>Remote Sensing</i>).
RADARSAT-2, Sentinel-1A Requirement #6	A combination of these two sensors will provide C-band coverage over Asia-RiCE sampling sites.
Contributing	ALOS-2, RISAT-1, RESOURCESAT-2, COSMO-SkyMed, TerraSAR-X, CBERS-4, Sentinel-2A
Future	RCM, RISAT-1A, CBERS-4A

Table 4 GEOGLAM Phase 1 Moderate Resolution (10 to 100m) Data Streams

Fine Resolution: 5 to 10m

RapidEye will be used as a part of a sampling strategy being put in place to reduce the reliance on crop extent coverage by the Landsat (and eventually Sentinel-2) data streams.

RapidEye Requirements #7 and #8	RapidEye will provide optical and SWIR data over refined sampling sites (rs and rs2) discussed in Section 3.4. Data over rs sites will be monthly, three times in season. Data over rs2 sites will be weekly, a minimum of once every two weeks.
Contributing	SPOT-5 (ending 2015), Sentinel-2A
Future	Sentinel-2B

Table 5 GEOGLAM Phase 1 Fine Resolution (5 to 10m) Data Streams

Very Fine Resolution: <5m

At present, no very fine resolution core data streams have been identified, though **Pleiades** could be evaluated as a part of early GEOGLAM phases.

No Missions Requirement #9	-
Contributing	Pleiades
Future	

Table 6 GEOGLAM Phase 1 Very Fine Resolution (<5m) Data Streams

5 Next Steps

As outlined in Section 1.2, GEOGLAM has evolved to employ a “community centric dynamic implementation” plan. As such, the CEOS strategy has adapted by becoming responsive and reactive. In addition, CEOS representation within GEOGLAM governance has grown clearer since CEOS Plenary 2014 (Tromsø), with representation on both the Advisory Committee and the Implementation Team. This helps to provide CEOS with assurances that its support and investment is recognised, and is commensurate with the development and maturation of GEOGLAM.

Several follow-up items for CEOS are proposed:

- That the 29th CEOS Plenary (November 2015, Kyoto, Japan) endorse the continuation of the CEOS Ad Hoc Working Group on GEOGLAM to continue to manage CEOS support and interactions with GEOGLAM.
- That the CEOS lead agencies for GEOGLAM (NASA, CNES) continue their strong leadership of the Ad Hoc Working Group.
- That the Working Group will coordinate implementation, and provide an update to SIT-31 (April 2016, ESA/ESRIN). The update will cover the implementation of acquisitions for GEOGLAM, progress on data access and dissemination, and the development progress of the GEOGLAM Initiative.
- That the Working Group will provisionally target an update to this document for endorsement at the 30th CEOS Plenary (2016, Australia).