Essential Agricultural Variables for GEOGLAM – *White Paper*

Purpose of Document

The purpose of this document is to provide the policy context and background behind the development of Essential Agricultural Variables for GEOGLAM (EAVs). It is intended to support the work of the EAV Working Group of the GEOGLAM Thematic Coordination Team on Earth Observations Data Coordination to develop the EAVs and their technical specifications. It will be brought to CEOS to investigate mechanisms for collaboration and implementation of this framework.

Responding to an Evolving Policy Environment

The main objective of GEOGLAM is to reinforce the international community's capacity to produce and distribute relevant, timely, and accurate information on agricultural land use and production at national, regional, and global scales, using Earth observation (EO) data, toward enhancing knowledge and improving sustainable decisions related to agriculture and food security. Figure 1 represents this Data to Sustainable Decisions Continuum for GEOGLAM. Foundationally, we work with the Committee on Earth Observation Satellites (CEOS) and space agencies to obtain data in a form that meets our requirements for extracting variables, then we convert the data into information products that support more complex information generation that addresses our policy mandate. This information is made available to our user communities to support better, more-informed, and sustained decision making around programs and policies in the agriculture and food security realm. The diagram also identifies the principle actors at each level (left side), with engagement across different bodies within CEOS underpinning the data through variable steps in the process.

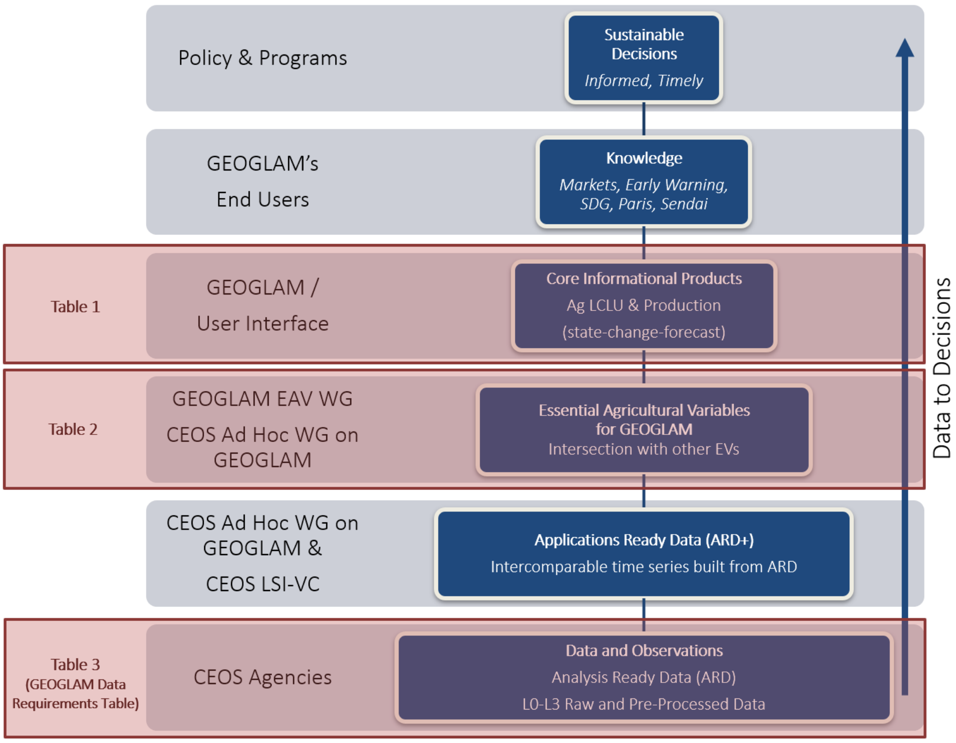

Figure 1. The GEOGLAM Data to Sustainable Decisions Continuum, with actors identified on left

Since 2011, the GEOGLAM community has grown at a steady pace, collaborating with more and more international initiatives, programmes, and projects. GEOGLAM has been successful in integrating Earth observations with place-based expertise to produce qualitative assessments of crop condition to support markets in line with our mandate through the 2011 G20 Action Plan on Food Price Volatility and Agriculture. These information products have been provided to the Agricultural Market Information System (AMIS) and published as part of the monthly AMIS Market Monitor (http://www.amis-outlook.org/amis-monitoring) since 2013. The GEOGLAM Crop Monitor for AMIS (CM4AMIS) provides information on four major commodity crops (maize, rice, wheat, and soybean), in countries that account for over 80% of their global production.

Building on the utility and impact of the CM4AMIS, GEOGLAM launched the Crop Monitor for Early Warning (CM4EW). The CM4EW focuses on countries at risk of food insecurity, as well as their relevant crops and drivers. Launched in February 2016, this activity is a response to calls from, -- and was built in tandem -- with, the early warning community, including the Famine Early Warning Systems Network (FEWSNET), the European Commission's Joint Research Centre (EC JRC), and the World Food Program (WFP). The G20 has responded positively to this expanded scope of GEOGLAM activities, with the 2018 G20 Agricultural Ministers Declaration explicitly recognizing GEOGLAM as, "among the key mechanisms to promote transparent markets and food security" (July 2018, Buenos Aires).

GEOGLAM is widely viewed as a reliable and credible source of information on crop conditions for markets and food security early warning. Over time, however, the priorities of the national and international organizations that GEOGLAM serves have also evolved. Demand has increased for quantitative estimations of croplands and rangelands, with clear impacts on data production and R&D activities. Meanwhile, in the policy domains, multiple new heavyweight policy drivers have emerged, including the United Nations 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs), the Paris Accords (the UN Framework Convention on Climate Change), and the Sendai Framework for Disaster Risk Reduction. Consequently, as we look toward solutions for humanity's problems (Rittel and Webber, 1973), an approach is needed that supports integration across science and policy domains. By extension, as a community GEOGLAM must have a way to simplify complexity, scope activities and provide clarity to communicate our potential contribution to custodial agencies.

The Case for Essential Agricultural Variables for GEOGLAM

The world has agreed to 17 Sustainable Development Goals (SDGs), supported by 169 targets, that are in turn fed by an initial and still growing set of 230 indicators (United Nations, 2015). Each indicator relies on existing and new multiple data streams, often spanning multiple science domains for its development (Reyers et al, 2017). National, regional, and global success toward achieving these multi-thematic and multi-scalar policy frameworks will require leveraging complementary and overlapping activities (Pradhan et al., 2017), from data through to decisions. The GEOGLAM community understands that the fundamental datasets upon which we rely can be brought together to create knowledge to support a wide range of policy challenges, both within and across science domains. This will require moving our monitoring to a more quantitative domain in both space and time. In this vein, GEOGLAM needs to clearly define the minimum set of variables we require to meet current and evolving policy drivers. Progress in systems theory in other science domains, originally led by climate (Bojinski, 2014); then biodiversity (Proença, 2017); and water (Lawford, 2014), suggest that the development of essential variables (EVs) may provide an approach that can be adopted by our community. Beyond our own community, it is an approach that supports communication and integration across science domains, while promoting a focused approach within the GEOGLAM scope of agricultural monitoring.

GEOGLAM aims to produce information on the current state of, and monitoring change in, agricultural land cover and land use. In the GEOGLAM context, these state variables track essential aspects of agricultural production and can be considered Essential Agricultural Variables (EAVs) for GEOGLAM. In the Data to Sustained Decisions Continuum (Figure 1), EAVs sit just above data and are precursors to higher information products such as crop type and yield. In essence, EAVs represent information "building blocks" that are rudimentary indicators of state and change in our domain and as such, these low-level indicators can be built up and integrated with other information for monitoring across multiple policy dimensions (e.g. SDGs, Paris Accord, and Sendai).

If the broader GEO community adopts the concepts and language of EVs, as already evidenced in other communities, the United Nations Interagency Expert Group on Sustainable Development Goals (IAEG-SDGs) that is tasked with developing SDG indicators and methodologies could provide the coordination to integrate EVs from multiple domains to measure and address complex problems that require integrated solutions. However, given communication gaps between the largely statistical IAEG-SDGs and the EO community, this is not a *fait accompli*, and is currently being addressed through efforts by GEO (EO4SDGs), CEOS, and through national intervention. Nevertheless, if the GEOGLAM community does not begin work on our EAVs now, we will not be ready to contribute.

Setting new policy drivers aside, for the G20 alone, EAVs are required to grow GEOGLAM activities to become more quantitative to meet the evolving needs of our original clients around market information and early warning for food security.

Defining GEOGLAM Essential Agricultural Variables

During early phases of GEOGLAM, a specific set of information needs and related data requirements were identified in what has become known within our community as the "Defourny Diagram" (Defourny, 2010; Whitcraft et al., *RSE in review*). This diagram links sensor agnostic, spatiotemporal requirements to the desired information outcomes or "use" (Figure 2). Although the identified spatial and temporal resolutions have improved and will continue improving in keeping pace with technological capacity (for example, we are moving from a >250m observatory to a <30m observatory thanks to Sentinel-2, Landsat, Sentinel-1, and others), the Defourny Diagram has nevertheless remained a relevant and concise articulation of the relationships between EO and use. In the case of the EAVs, the Defourny Diagram has provided a canvas for identifying the core information domain of GEOGLAM.

Figure 2. The Defourny Diagram demonstrates that the core information products, uses, and underlying data have not changed substantially since 2010. Their reinterpretation in the Essential Variable, policy, and decision framework context has been clarified and simplified.

Surveys and discussions preceding and during the GEOGLAM Operational Requirements Meeting identified high priority information products, including cropland mask, crop type map and planted area, yield forecast, and crop growth condition assessment. In a similar survey deployed by the Rangeland and Pasture Productivity (RAPP) group, rangeland/pasture cover and rangeland/pasture biomass were among the most highly valued products. Meanwhile, community members are mapping GEOGLAM information products to our policy drivers, including markets, early warning, SDGs, Paris Accord and Sendai. Papers have been submitted for publication that begin to link GEOGLAM activities to SDG's (Whitcraft et al., *RSE in review*, Whitcraft et al., *AGU in review*, and Becker-Reshef et al., *RSE in review*). Work is underway through the NASA Harvest Consortium to quantify the impact of EO in general, and GEOGLAM in particular, on agricultural markets.

Some thought has gone into what a list of EAVs for GEOGLAM would contain, but much more work is required to more rigorously define them. It is the initial mission of the EAV WG to:

a. reach consensus on the information products and EAVs;
b. reach consensus on the spatial, spectral, and temporal resolutions, and latency of the underlying observations;
c. reach consensus on the levels of pre-processing necessary to empower routine EAV creation by agricultural monitoring entities (ARD and ARD+);
d. clearly document the decision support and policy need;
e. work with CEOS to meet the requirements.

An initial set of Core Information Products and EAVs for GEOGLAM identified below (Tables 1 and 2). Please note these are draft, incomplete and not ratified by the GEOGLAM Community.

Table 1: Core Information Products for GEOGLAM

	Core Information Product (TBC)	Spatial Resolution, Accuracy, and/or Precision	Frequency of Production	End Use: Knowledge & Sustainable Decisions Supported
1	Cropland mask	300m to 3m	Monthly within season	State and Change: Federal/State land use policy; infrastructure investment; statistics; SDGs, climate change impacts
2	Irrigated vs non irrigated cropland	300 to 3m	seasonal	Water management and monitoring; SDGs (water use efficiency)
3	Crop type map	300m to 3m	Monthly within season	Fed/State/Int'l Market information; infrastructure investment; supplement/replace survey statistics; SDGs, climate change impacts
4	Crop type area	Admin Level 1, +/-	Every 2 months	Market information; supplement/replace survey statistics

		10%	within season	on production; logistics planning; food security-early warning
5	Crop condition	300m to 3m	1-2 weeks	Market information; food security-early warning; Fed/state policy and program response; production insurance
6	Crop yield forecast	Admin Level 1, +/- 10%	Monthly throughout season(s)	Market information; supplement/replace survey statistics on production; logistics planning; food security-early warning; SDGs; climate change impacts
7	Crop Yield Estimation	field level	Seasonal, post-harvest	Market information; supplement/replace survey statistics on production; logistics planning; food security-early warning; SDGs; climate change impacts
8	Rangeland and pasture mask	300m to 3m	Seasonal	State and Change: Federal/State land use policy; statistics; SDGs, climate change impacts
9	Rangeland and pasture condition	300m to 3m	Monthly throughout season(s)	Food security-early warning; SDGs; climate change impacts

Table 2: Essential Agricultural Variables for GEOGLAM

	Essential Agricultural Variables for GEOGLAM (TBC)	**Spatial Resolution, Accuracy, and/or Precision**	**Frequency of Production**	**Core Information Product Supported**
Primary	NDVINDVINDVI (and related vegetation /chlorophyll indices)	300m to 3m	Weekly to 10 days composites	Crop condition Yield forecast Rangeland condition
	Above Ground Fresh / Dry Biomass	300m to 3m	Weekly to 10 days composites	Crop condition Yield forecast

				Rangeland condition
	LAI? fAPAR, fractional cover? ALB?	300m to 3m	Weekly to 10 days composites?	Crop condition Yield forecast Rangeland condition
	Crop development stages: emergence date, flowering date, maturity, harvest	300m to 3m	Ongoing annual assessment guided by crop calendars	Crop condition Yield forecast Crop type map Crop type area
	Field & Plot Delineation	+/- 10%	3-5 years	Crop mask Crop type map Crop type area Rangeland mask
Supporting (Ancillary Data and EVs)	Crop calendars (Range of seeding and harvest dates)	Admin Level 1, +/- 2 weeks	3-5 years	Crop condition Yield forecast Crop type map Crop type area
	Surface water mapping	Sub-field	Weekly	Crop Type (Too-wet-to-seed); others?
	Precipitation			
	Land Surface Temperature			
	Evapotranspiration			
	Surface albedo			
	Land Cover and Land Use (ECV)	1km to 3m		Rangeland mask
	Surface Soil Moisture	Sub-field	Weekly?	
	Cloud climatology			

Table 3: GEOGLAM Earth Observation Requirements

					Utility for Target Products**											
					Essential Agriculture Variables: Tier 0 and Tier 1								Supporting Variables			
***	Spatial Resolution	Spectral Range*	Effective observ. frequency (cloud free)	Extent	Within Season Crop Mask	Within Season Crop Type Mask	Crop (Type) Area Indicator	Crop Condition Indicators	Current Crop Phenology & Ag Practices	Biomass, LAI, fAPAR, fCover, NDVI, Height	Within Season Yield Forecast	End of Season Yield Estimation	Soil Moisture	ET, Water Use, LST	Usual Crop Calendars	Field delineation
				Target Product Update Frequency:	Monthly	Monthly	Mid of Season	Weekly	Weekly	Weekly	Monthly	End of Season	Daily	Daily	Every 5 years	Every 3 years
Coarse Resolution Sampling (>30m)																
1	100 - 1000 m	optical	Twice daily	Wall-to-Wall				X		L	L	L			L	
2	50-500 m	optical	2-5 per week	Cropland extent	X	X		X	L	L	L	L		X	L	
3	5-25 km	passive microwave	Daily	Wall-to-Wall				X		X	X	X	X	X		
4	30-100m	thermal	2 to 7 per week	Cropland extent		X		X		X	X	X	X	X		
Moderate Resolution Sampling (10 to 30m)																
5	10-30m	VIS NIR + Red Edge + SWIR	Weekly	Cropland Extent	X	X		X	X	X	X	X		X	X	L
6	10-30m	SAR dual polarization	2-4 per week	Cropland extent	X	X	L		X	X	X	X	X	X	X	L
7	10-30m	SAR coherence	2-4 per week	Cropland extent	X	X	L		X	X	X	X	X	X	X	L
8	10-30m	SAR Multifrequency	Weekly	Cropland extent	X	X	X		X				X		X	
Fine Resolution Sampling (5 to 10m)																
9	5-10m	VIS NIR + Red Edge + SWIR	Weekly	Cropland Extent	X	X	X	X	X	X	X	X		X		L
10	5-10m	SAR dual polarization	2-4 per week	Cropland extent (cloudy & rice)	M/S	M/S	X		M/S	X			X	X		
Very Fine Resolution Sampling (<5m)																
11	< 5m	VIS NIR	3/year (2 in + 1 out of season)	Cropland extent of small fields, every 3 years	S	S	M/S									M/S
12	< 5m	VIS NIR	1 to 2 / 3 years	Cropland extent												M/S
13	< 3m	VIS NIR	1 to 2 per month	Refined Sample of All Fields	S	S	X				X	X				M/S
14		SAR Multifrequency	Weekly	Cropland extent (cloudy)					X	X			X			