The Power of Synthetic Aperture Radar for Global Agricultural Monitoring

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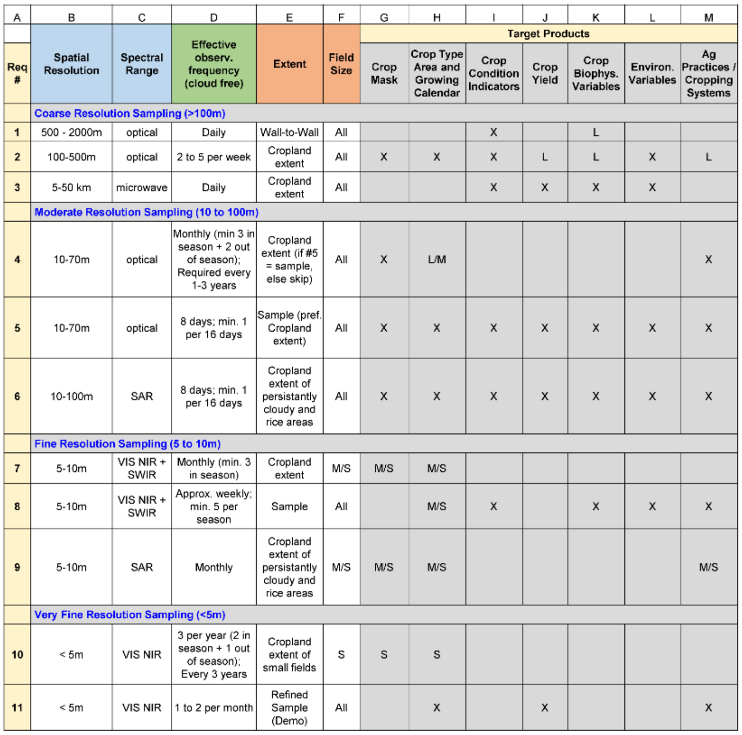
A changing climate means greater uncertainty for the agriculture sector due to variability in available water, fluctuations in temperature, and increased occurrence of extreme weather events. The impacts on crop conditions, crop production, and ultimately food supply can be devastating at national, regional, and even global scales. To frequently monitor the status of global crops across diverse landscapes, the remote sensing community within the Group on Earth Observations Global Agricultural Monitoring (GEOGLAM) Initiative has exploited the satellite-based data available to them – optical and synthetic aperture radar (SAR) alike – toward providing key information on crop conditions to decision makers. Still, there remain critical gaps in EO data and methods adoption, which could be bridged by:

- *A continued and expanded commitment by space agencies to provide fully free and open access to systematically pre-processed, analysis-ready data;*
- *Sufficiently frequent (SAR and optical) acquisition over agricultural areas (consistent with GEOGLAM's data requirements; Whitcraft et al., 2015 (Table 1));*
- *Space agency commitments to ensure data continuity for the coming decades, for SAR missions properly configured for agricultural/vegetation monitoring applications;*
- *Support for training and knowledge transfer surrounding SAR and SAR-optical fusion techniques for monitoring agriculture.*

Table 1: The GEOGLAM Satellite Data Requirements, developed by the GEOGLAM Community of Practice in tandem with the CEOS Ad Hoc Working Group for GEOGLAM (Whitcraft et al., 2015).



A	B	C	D	E	F	G	H	I	J	K	L	M
						Target Products						
Req #	Spatial Resolution	Spectral Range	Effective observ. frequency (cloud free)	Extent	Field Size	Crop Mask	Crop Type Area and Growing Calendar	Crop Condition Indicators	Crop Yield	Crop Biophys. Variables	Environ. Variables	Ag Practices / Cropping Systems
	Coarse Resolution Sampling (>100m)											
1	500 - 2000m	optical	Daily	Wall-to-Wall	All			X		L		
2	100-500m	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 3 in season + 2 out of season); Required every 1-3 years	Cropland extent (if #5 = sample, else skip)	All	X	L/M					X
5	10-70m	optical	8 days; min. 1 per 16 days	Sample (pref. Cropland extent)	All	X	X	X	X	X	X	X
6	10-100m	SAR	8 days; min. 1 per 16 days	Cropland extent of persistantly cloudy and rice areas	All	X	X	X	X	X	X	X
	Fine Resolution Sampling (5 to 10m)											
7	5-10m	VIS NIR + SWIR	Monthly (min. 3 in season)	Cropland extent	M/S	M/S	M/S					
8	5-10m	VIS NIR + SWIR	Approx. weekly; min. 5 per season	Sample	All		M/S	X		X	X	X
9	5-10m	SAR	Monthly	Cropland extent of persistantly cloudy and rice areas	M/S	M/S	M/S					M/S
	Very Fine Resolution Sampling (<5m)											
10	< 5m	VIS NIR	3 per year (2 in season + 1 out of season); Every 3 years	Cropland extent of small fields	S	S	S					
11	< 5m	VIS NIR	1 to 2 per month	Refined Sample (Demo)	All		X		X			X

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For agricultural monitoring, cloud cover can play havoc with monitoring initiatives where soil and crop conditions change on daily if not hourly temporal scales, requiring frequent observation to track crop evolution. As has been repeatedly touted by enumerable research papers and scientific presentations, SAR sensors have a key advantage over their optical counterparts: because they are active sensors that propagate energy at longer microwave wavelengths, SAR data acquisition is unaffected by the presence of cloud cover and is independent of solar illumination. Given this fact, the question remains as to why the uptake of SAR for operational monitoring in agriculture has been so limited.

The answer to this question is undoubtedly multi-faceted. First, the long revisit cycles (20-50 days) and restrictive acquisition plans of most space-borne SAR missions has meant insufficiently frequent data acquisitions and non-systematic geographic coverage. Second, early sensors provided only single dimensional data (one polarization and one frequency). The choice of single polarization (HH in the case of Canada's RADARSAT-1 and Japan's JERS-1; and VV in the case of Europe's ERS-1/2, as examples) was insufficient for crop monitoring. Second generation sensors (Europe's ENVISAT ASAR (launched in 2002); Japan's ALOS-PALSAR (launched in 2006); Germany's TerraSAR-X and Canada's RADARSAT-2 (both launched in 2007)) transmitted and received alternating pulses at H and V polarizations. With this, users gained access to not only dual polarization data but to the single most useful polarization for crop monitoring: the linear cross polarization (HV or VH).

This has greatly expanded the world of possibilities for agricultural monitoring utilizing SAR data. The scientific community has had these data in hand for just over a decade, but this short period has borne witness to great leaps forward in SAR methodologies. Research with RADARSAT-2 and the Europe Space Agency's recently launched Sentinel-1A has firmly and repeatedly demonstrated the capability of dual polarization modes (principally VV+VH, but also HH+HV) in identifying crop types. For example, Agriculture and Agri-Food Canada uses an integration of single frequency C-band RADARSAT-2 with optical data to deliver an operational annual crop inventory for the country, with an overall classification accuracy of at least 85% (Fisette et al., 2013; Figure 1). Meanwhile, scientists at CESBIO in France have demonstrated that crucial crop variables such as LAI and crop calendar/phenology can be retrieved from coordinated optical/SAR acquisitions or from SAR on its own, particularly in areas limited by cloud cover (Veloso et al.; Figure 2). In fact, research has shown repeatedly that a SAR-only solution to crop mapping is possible if two SAR frequencies are integrated. In a Canadian study on crop classification, an integration of C- with L-band SAR delivered overall accuracies well above 85% (McNairn et al., 2009). It is clear that a coordinated, multi-mission virtual constellation capable of acquiring some combination of C, X, and L-band data would facilitate multi-frequency SAR integration, an immensely powerful tool for agricultural monitoring.

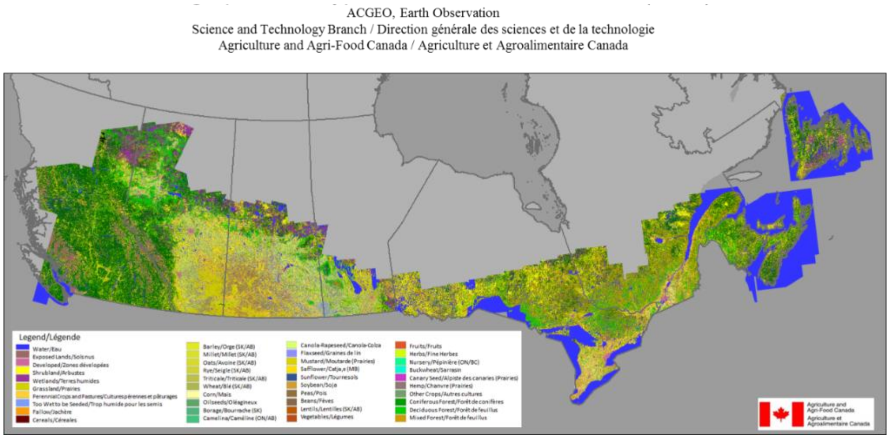


Figure 1: The AAFC Crop Inventory for 2014, which integrates optical data together with RADARSAT-2, in an operational context.

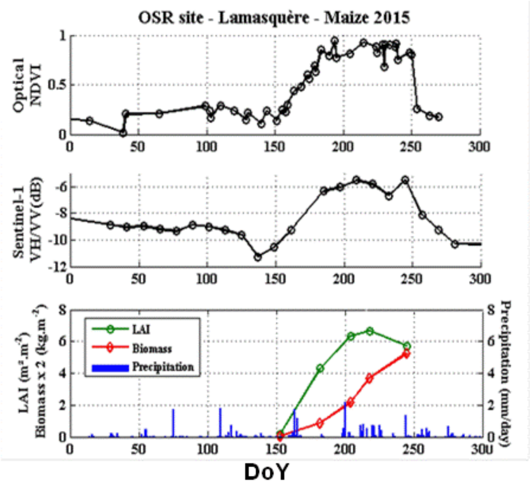
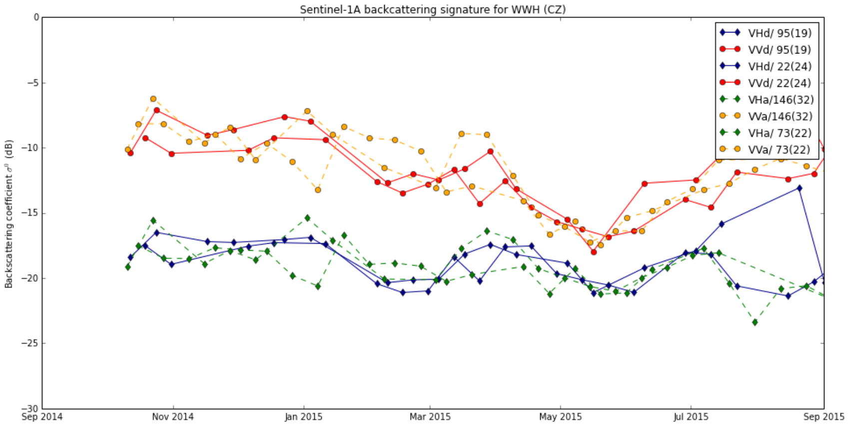


Figure 2: Temporal variation of measurements in 2015 over a maize field in Lamasquère, a JECAM site in southwestern France, demonstrating that Sentinel-1 SAR data can be used for monitoring crop growth together with or in place of optical data such as Landsat, SPOT, and Sentinel-2 data (Veloso et al. 2016). In order to have a dense temporal NDVI, the use of 4 different optical systems were needed, whereas these gaps are not present for SAR systems. Top: NDVI derived from 4 optical satellites: Landsat 8, Formosat 2, Deimos, SPOT 4 (Take 5). Middle: Ratio of VH and VV backscatter from Sentinel-1. Bottom: Precipitation (in blue), Biomass (in red), and LAI (in green). (Veloso et al., 2016)

The 2014 launch of the C-band Sentinel-1 mission is ushering in a new era for SAR-based agricultural monitoring. Its data are provided under a full free and open license, which guarantees a much easier availability of SAR data to the user community than those that are provided under restricted or limited scientific licenses. Furthermore, Sentinel-1 has a much shorter revisit frequency (12 days, instead of 24 days for Radarsat-2, 35 days for ERS-1/2, and 46 days for JERS and ALOS-PALSAR), which is closer to the established GEOGLAM data requirements for following the dynamics of the crop growth cycle (Whitcraft et al., 2015; Table 1). Sentinel-1B, a twin of Sentinel-1A, will be launched on 22 April 2016, and stands to double the acquisitions already accomplished through Sentinel-1A. In fact, due to overlapping relative orbits of Sentinel-1A, the time series of SAR for agriculture is so sufficiently dense (Figure 3) that the new acquisitions from Sentinel-1B could be allocated to other cloud-limited or otherwise data poor areas of the Earth – a major step toward meeting Earth observation requirements for global agricultural monitoring (Figure 4).

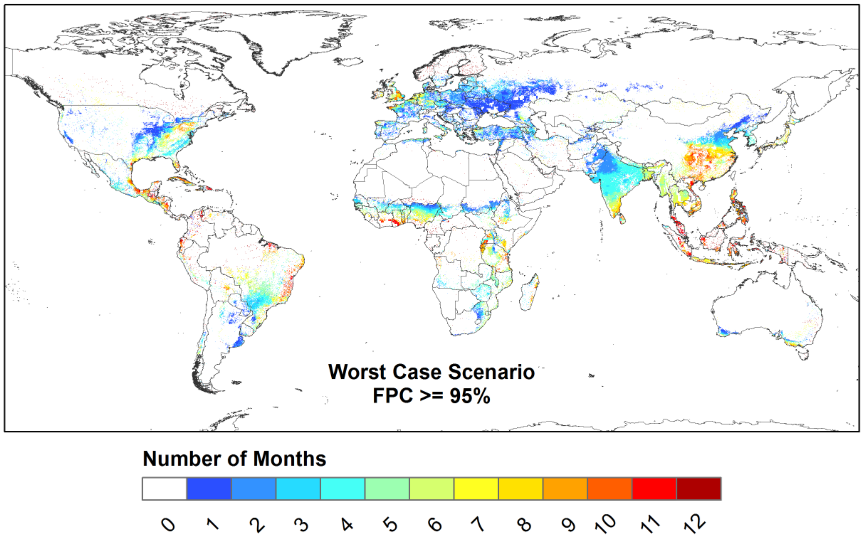
Figure 3: A time series of extracted sigma_0 (backscattering coefficient) for a winter wheat field in Czech Republic covered by 2 ascending and 2 descending relative orbits of Sentinel-1A. This has led to 97 observations over less than one year, much denser coverage than the 30 observations expected by the 12 days revisit alone. Note that many areas in Europe are covered by 3 relative orbits, meaning 50 to 60 observations, still sufficient to monitor agriculture. (Courtesy of G. Lemoine, JRC-MARS)



However, translating such engineering advances into scientific accomplishments and finally operational adoption takes time, but could be accelerated and encouraged by open data policies, reliable and consistent data acquisition, and through support of communities engaging in training and methods transfer (e.g. through training of trainers). There is much work left to do, in particular in disseminating these advancements to the operational agricultural monitoring community, as well as to the more general community of data providers and value-added industry. These groups have frequently overlooked SAR as a solution for monitoring agriculture due to its perceived complexity as well as to the relatively low priority of agriculture in mission and acquisition planning stages.

GEOGLAM and its partners, through concerted operational research and development efforts led by the Joint Experiment on Crop Assessment and Monitoring (JECAM), Asia Rice Crop Estimation and Monitoring (Asia-RiCE) and associated activity ESA GeoRICE, and Stimulating Innovation for Global Agricultural Monitoring (SIGMA) initiatives, are committed to continued demonstration of the utility of these data in operational crop monitoring domain and to facilitating the transfer of these methodologies along the research to operations (RTO) continuum via capacity development, training, and knowledge transfer. To achieve this, we will continue to seek the support of the Committee on Earth Observation Satellites (CEOS) and its space agencies for both the provision of SAR data from existing systems as well as the consideration of agricultural production and food security monitoring in the planning of subsequent SAR missions.

Figure 4: The number of months for which there is a failure in capabilities of existing moderate spatial resolution optical remote sensing to meet EO data requirements for agriculture monitoring, due to persistent cloud coverage during important periods of the agricultural growing season. These are the areas and times which would benefit greatly from SAR acquisition. This analysis is based on a <5% acceptable cloud coverage threshold. (Whitcraft et al., 2015)



Citations

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