Application Form

GEO-Amazon Earth Observation Cloud Credits Programme

Title: AWS4AgriSAR-Crop inventory mapping from SAR data on cloud computing platform

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2. Collaborators

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<tr><td colspan="4">Focus Area:
The research group deals with the development of methodologies and applications with Earth Observation Sensors (EOS) with particular focus on synthetic aperture radar (SAR) polarimetry and interferometry technologies.

Researchers have demonstrated successful use of SAR polarimetry for crop inventory mapping, bio-geo physical parameter retrieval over multi-test site experiments. Towards operational agricultural applications with SAR, the group is involved with the Joint Experiment for Crop Assessment and Monitoring (JECAM) SAR Inter Comparison Experiment to benchmarking and advocate a set of best technical practices and recommendations for global agricultural analysis using EO data.</td></tr>
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Researchers from this group are actively involved in the development of the state-of-the-art PolSAR scattering power decompositions (viz., AG4U, SDY4O, S-Ω) for quad- and compact-pol radar data. Recent development of cloud-based SAR processing pipe-line (Sen4Rice) for Sentinel-1 in the European Copernicus program enabled a way to monitor rice in Asian subcontinent at operation scale. Particular interest in machine learning and cloud-processing of SAR data for ecosystem studies have become influential in this application field, with evident interest for EO- and agri-industries.

B. SST Group, IUII, Universidad de Alicante, Spain

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Focus area:

The major focus area of the SST group at the University of Alicante is remote sensing with synthetic aperture radar (SAR), and the most relevant contributions correspond to both technology and applications.

At the technology side, contributions are made decisively to the adoption of radar techniques in 3D near-field imaging thanks to the formulation and development of an innovative and efficient algorithm for image generation in these conditions (common in proximity sensors, laboratories, through-the-wall systems, security checks, anechoic chambers, etc.). Currently most algorithms being developed for such systems, despite advances in technology (MIMO, phased arrays, etc.), rely on the framework developed in that original approach.

Regarding applications, this lab has been the first to demonstrate the sensitivity of polarimetric SAR data acquired by satellites to the development stages of agricultural crops. Based on that sensitivity, new approaches are developed that enable the retrieval of crop phenological stage and other crop condition indicators (e.g. plant height) relying only on the exploitation of radar data. These developments opened the way to build operational agriculture monitoring services (not only for crop-type mapping) based on the constant acquisition scheme provided by SAR satellites (e.g. Sentinel-1 in the European Copernicus program). Publications in this topic have become seminal in this application field, with evident interest for society (market predictions, grants, subsidies, insurance, etc.) and agronomic companies (precision farming). Research team has shown notable contribution by its leadership of the work packages related to agriculture in several ESA funded projects (POLSAR-Ap, SInCohMap, L-band EXPRO+, etc.).

3. Executive summary

Title	**AWS4AgriSAR-Crop inventory mapping from SAR data on cloud computing platform**

Crop yield is a direct indicator of national food security that enables decision makers with beneficial marketing strategies during the crop growing season. Timely crop growth information at a field scale can assist farmers with various agronomic management decisions on fertilizer application, irrigation scheduling, and pesticide use by reducing the risk of disease [1] while maximizing grain yields and minimizing agricultural input.

In India, crop risk assessment and yield gap are being monitored under a national scheme with the flagship of the Pradhan Mantri Fasal Bima Yojana (Prime Minister Crop Insurance Scheme: http://agri-insurance.gov.in). It has progressively grown within a couple of years, where 1.12 crore farmers are insured with a total payout of Rs. 12959.10 crore (INR) under the PMFBY in the 2016-17 financial year. Within the PMFBY's operational guidelines, state governments' authorities are required to carry out crop cutting experiments (CCEs). These CCE based yield data is then submitted to insurance companies within a month after harvesting. Theoretically, if the states provide their full share of premium subsidy along with yield data within a reasonable time, farmers can receive their claim payment timely.

Unfortunately, the above timeline within a crop season is seldom maintained by most of the states. According to the Ministry of Agriculture and Farmer's Welfare, Govt. of India, in recent cases, states are unable to maintain the timeline of PMFBY. This is majorly due to undue delays in the furnishing of yield data by each state. Furthermore, the CCE-based yields are themselves prone to questions by insurance companies which makes CCE a major weakest links in PMFBY. Crop loss assessment has to not only be timely but also reasonably accurate to inspire confidence among the insurance companies. Although CCEs can give a reliable average yield rate, when it is used for payment individual farmer for crop insurance claims, it is rarely the best. This might be because the samples of CCEs required in a crop yield assessment is unfortunately based on sample averaging. On the contrary, the insurance scheme seeks individual loss assessment. Furthermore, carrying out a vast number of CCEs over a large area within a single season in a short period has proven to be the biggest challenge in the implementation of the insurance scheme.

In this regard, the remote-sensing-based system gives a better opportunity by providing crop growth across large areas with frequent sampling during a crop season [2]. Satellite-based Earth observation (EO) data can be acquired over large areas at regular intervals and therefore provide crop condition information with possible spatio-temporal extension. Optical remote sensing data derived vegetation information is found to be suitable for such case and has good correlation with yield. However, in the Indian monsoon condition, pervasive cloud cover makes it intangible for mapping or monitoring crop with optical remote sensing. On the contrary, Synthetic Aperture Radar (SAR) data has drawn considerable attention for agricultural applications due to all weather monitoring and sensitivity towards dielectric and geometric properties [3], [4]. As SAR response be influenced by crop canopy characteristics which vary during the phenological stages of the crop, thereby, it is likely that SAR can discriminate crops growth stages and have proven sensitive to several crop biophysical parameters (Leaf Area Index, biomass, canopy height). In this proposed work, the potential of SAR data will be exploited to estimate crop growth stages (phenology) and estimate plant growth descriptors such as crop biophysical parameters (e.g., Leaf area index, biomass, etc.) which in turn helps in yield gap assessment.

Operational monitoring through these crop growth descriptors benefits from Earth Observation (EO) data with high temporal revisit and extended spatial coverage. Frequent satellite revisit is necessary to monitor critical phenological stages throughout the crop season. In this context, the recently launched C-band Sentinel-1 SAR constellation offers global high-resolution imagery at an unprecedented spatial and temporal resolution. Such a configuration meets EO requirements for global agricultural monitoring. Sentinel-1A and 1B provide 6-day temporal repeat data which could contribute significantly to the monitoring of crop dynamics.

Unfortunately, the processing of dense time series of Sentinel-1 like data for operational purposes would be constrained by computational challenges due to such a high volume of data. Even for regional scale monitoring, the SAR research community is challenged in its handling of the amount of data delivered from these operational missions. As a result, several space agencies have initiated the adoption of commercial cloud computing platforms. These platforms are being explored as a way to archive and disseminate large volumes of data, efficiently. For example, Sentinel-1 data are available on Google Earth Engine (GEE) clouds as well as Amazon Web Services (AWS), and the data are regularly synchronized with the Sentinel Open Hub. Similarly, for the upcoming NASA-ISRO SAR (NISAR) mission, the Alaska Satellite Facility (ASF) DAAC is exploring a preliminary prototype of a cloud-based system. This approach is currently being tested with Sentinel-1 (~5GB of data volume per frame) as a surrogate to NISAR data (~25GB per frame).

In a cloud-based system such as AWS, users can fetch and process high volumes of SAR data directly in the cloud, instead of downloading and processing in a local system. Data processing can be performed in parallel on AWS's computational infrastructure, dramatically improving processing efficiency, and opening up valuable opportunities for end users. To date, studies on crop classification, global scale crop LAI products from MODIS, crop yield gap assessment, etc. have demonstrated the use of cloud platforms and the viability of this cloud computing framework. However, SAR data have not been fully explored in such a cloud platform for delivery of crop inventories. Hence, the proposed project would benefit from AWS's computing infrastructures efficiently.

Notably, early estimates and crop condition assessment would reduce the agricultural risk. This can benefit the Sendai Framework directly for Disaster Risk Reduction's global targets of enhancing international cooperation to developing countries (India) through adequate and sustainable support to complement national actions (Disaster Management Act -2005). Also, the proposed project would enhance disaster preparedness for an effective response which is one of the four priorities for action under the Sendai Framework. It is important here to note that the analysis ready data products (crop growth descriptors) can directly help to fulfill the climate change scenarios to access the effect on crop yield gap which is one of the essential elements of the Paris Agreement and the United Nations' sustainable development goals.

As a partner of a sustained international network of agricultural monitoring under GEO Global Agricultural Monitoring (GEOGLAM)-JECAM, we are developing cross-site experiments to benchmark a set of best technical practices and recommendations for global agricultural analysis using SAR data. The proposed project would utilize these practices to showcase operational activity.

Data obtained from remote sensing platforms and crop simulation models can allow government agencies and private industry to monitor crop condition and yield gap assessment within a crop season in an efficient way, as compared to the conventional crop cutting experiments (CCEs) over agricultural fields in existing National crop monitoring protocols. In this context, the proposed framework through collaborative research can provide an efficient methodology for monitoring crops and risk assessment in all-weather condition with the advent of radar remote sensing technology and AWS's computational framework.

The sensitivity of SAR backscatter signal to crop biophysical parameters is efficient to model and eventually estimate biophysical parameters indicative of crop condition. These crop biophysical parameters can be used either directly or through assimilation into yield models to estimate grain yield. Furthermore, crop monitoring with an operation context using the recently launched Sentinel-1 SAR system and the upcoming SAR missions like Radarsat Constellation Mission (RCM), NASA-ISRO SAR (NISAR) mission, RISAT-1A, and 1B have immense potential to accurately monitor crop dynamics in terms of the retrieved biophysical parameters. With a robust validation strategy, the proposed methodology can be scaled up for such an operational monitoring system which can strengthen the weakest links of national crop monitoring systems by reducing the uncertainties in yield gap assessment.

The goal of the proposed project is to evaluate the potential and transferability of the crop inventory development from a point scale to a regional test site with PolSAR data in AWS's processing chain. This research proposes operational exploitation of SAR data to produce high-resolution crop specific maps as value-added products.

4. Project plan

The proposed work has majorly two components for action: 1) crop phenology estimation, and, 2) retrieval of crop biophysical parameter, which can be further linked to the crop yield gap assessment. The proposed framework will consider a validation module along with these two components. In-situ measurements (crop information, ground measured biophysical parameters) and satellite data will be the prime inputs to this framework. The schematic diagram of the proposed framework is shown in Figure 1.

4.1. Action-1: Crop Phenology Estimation

The proposed approach exploits the known sensitivity of SAR observables to the morphology of the plant canopy to differentiate the physical changes in the crop during its phenological development. Identification of these phenological changes is essential for monitoring crop condition and planning strategic agronomic management. For instance, fertilizer application could be terminated if the end of the vegetative stage of the crop can be estimated. Fertilizer application is no longer useful during the end of vegetative growth since it can increase weed infestation. A recent study by Wiseman et al. [1] and Pacheco et al. [5] suggest that the flowering of canola (oil-seed crop) and transitioning to pod filling stage can be identified promisingly with C-band SAR observables. Identification and determination of time-span of these stages are essential for canola diseases risk caused by *Sclerotinia* stem rot. Risk of contamination by *Sclerotinia* is greatest when wet conditions prevail during the flowering stage of the plant. Spraying for maximum protection should take place when the canola bloom is at 20% - 30%.

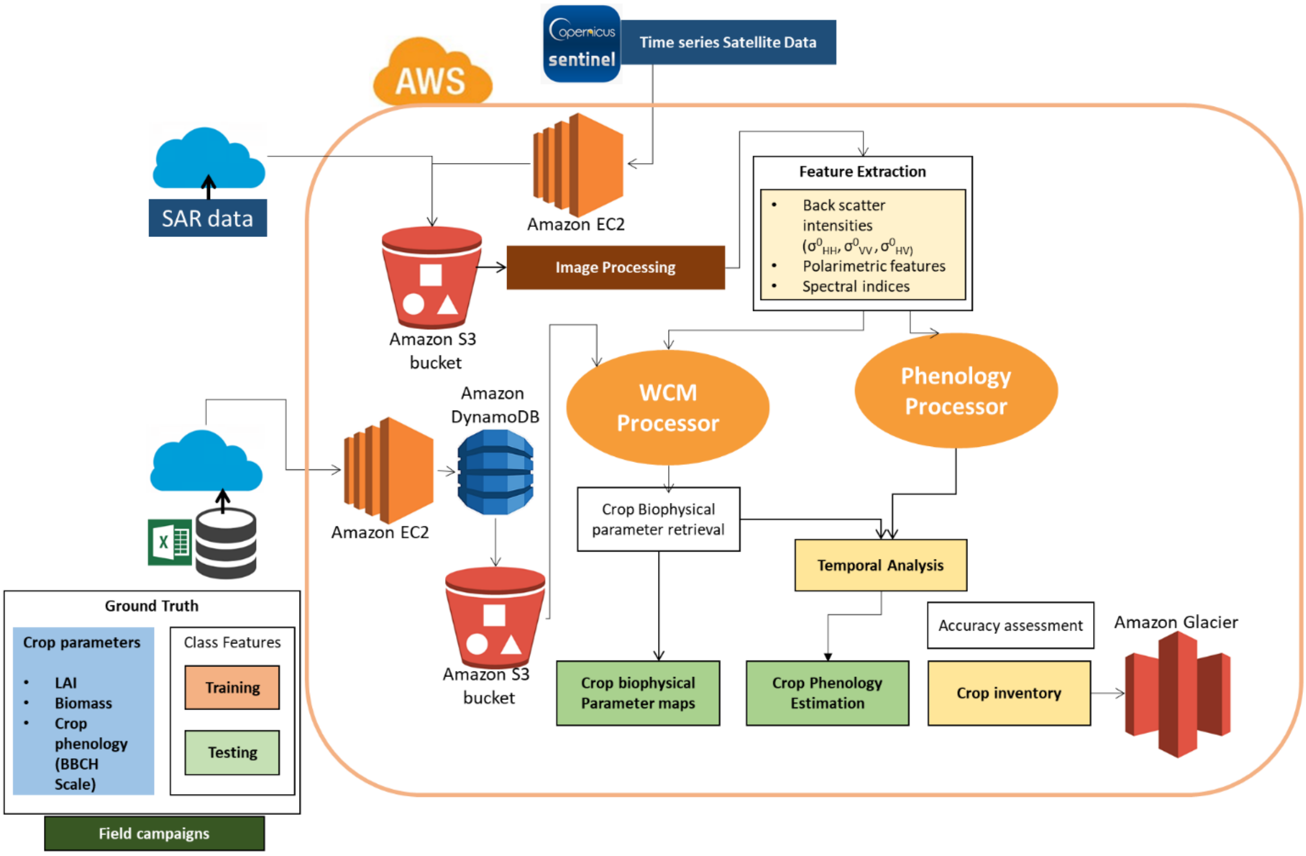

Figure 1. Schematic framework for crop phenology estimation and biophysical parameter retrieval using SAR data on AWS cloud infrastructure.

Wiseman et al. [1], also reported an increase in SAR response at the ripening stage of wheat which signifies the onset of harvesting the crop. The increase in response of SAR observables (e.g., cross-pol backscatter intensity, volume scattering) at the time of booting of wheat flag leaf may serve as an indicator for optimal timing of fungicide application. Common diseases such as fusarium and septoria blight start early in the phenological cycle when wheat is in the flag leaf stage. Moreover, at a high spatial resolution, it might also be possible to observe phenological delay within a field, which might arise due to uneven distribution of agricultural inputs or stagnant water condition or a salinity issue.

Phenology retrieval with polarimetric SAR data was first introduced by Lopez-Sanchez et al. [8] and modified further as a dynamic system problem [9]. Phenological evolution of various crops has been studied in the recent decade with SAR observables in a multi-temporal scale. With the availability of ESA's operational Sentinel-1 dual-polarimetric SAR data, a recent study has proven to be an effective way to monitor rice stages in a larger spatial extent [6], [7].

In general, the estimation of phenological stages can be regarded as a classification problem, where each class corresponds to a phenological stage. In this context, phenological stages can be separated in the observation space defined by a set of SAR polarimetric parameters. Therefore, the strategy for defining the retrieval algorithm consists in the selection of a set of polarimetric parameters and their corresponding ranges for each phenological stage. Later, polarimetric parameters can form a decision space where various stages can be clustered. Here, machine learning based clustering algorithms (Random forest or decision tree or support vector machines) can be applied to get an automated approach for phenology estimation.

4.2. Action-2: Crop biophysical parameter estimation

Crop biophysical parameters viz. leaf area index (LAI), biomass and height are the descriptors of plant growth status and serves as the key input to yield forecasting models. LAI is correlated directly with canopy foliage and canopy structure. The wet biomass is related to canopy water content and carbon accumulation during the crop growth stages. To retrieve vegetation information from SAR observations, a model is first required to simulate backscatter intensities for a crop canopy. This model can then be inverted to estimate canopy characteristics. In the literature, a semi-empirical water cloud model (WCM), proposed by Attema and Ulaby [10] has been widely used to retrieve vegetation parameters. The retrieval of crop biophysical parameters has been investigated using the semi-empirical WCM model in several studies for various crops using satellite data over the large agricultural area [11]-[14].

The crop parameter retrieval using WCM involves model calibration and followed by the inversion process. However, the retrieval of biophysical parameters using such a model is hindered by the ill-posed nature of the problem [14]. The traditional inversion techniques including numerical optimization and look up table (LUT) search was investigated in several studies [13], [14]. However, the process is computationally intensive to arrive at a stable solution and suffers from the lack of good generalization capacity which makes the retrieval of biophysical variable contentious for an operational context [15].

Alternatively, machine learning regression techniques with a regularization method will be applied in this proposed work which may provide a stable and optimum solution for the ill-posed problems of WCM inversion [16] [17]. In a recent experiment over the JECAM test site at Canada, Mandal et al. [17] well illustrated that the multi-target regression techniques estimate a functional relationship between a set of variables (LAI and biomass) and the corresponding target (i.e., backscatter coefficients). Typically, machine learning regression techniques can map the strong nonlinearity of the functional dependence between the biophysical parameters and the observed backscatter intensities. Moreover, these algorithms are very fast to apply, once trained. Hence, it might be a more suitable technique for operational applications.

Furthermore, the relationship between LAI and wet biomass indicates that the multi-target regression (MTRFR) successfully preserves the relationship between the crop parameters during the model inversion process [17]. In addition, the MTRFR based inversion technique, which incorporates the inter-correlations between the biophysical parameters, yielded improved inversion results as compared to than single target Random Forest Regression (RFR) and Look-up Table (LUT) based approaches. Hence, the multi-target approach will be of particular interest for operational implementation, given that simultaneous retrieval of multiple interdependent biophysical parameters is possible.

In the context of operational implementation, the recently launched C-band Sentinel-1 SAR constellation offers global high-resolution imagery at an unprecedented spatial and temporal resolution. Such a configuration meets EO requirements for global agricultural monitoring. Copernicus' Sentinel-1A and 1B provide 6-day temporal repeat data which could contribute significantly to the generate such crop inventories. Hence, it is important to evaluate model inversion methodologies to test their accuracies for operational use.

Unfortunately, the processing of dense time series of Sentinel-1 data for operational purposes would be constrained by computational challenges due to such a high volume of data. Even for regional scale monitoring, the SAR research community is challenged in its handling of the volume of data delivered from these operational missions. Amazon cloud service would be a better option for such big data processing for crop monitoring. In a recent study, Mandal et al. [18] showcased a cloud based processing pipeline for monitoring rice crop at regional level using Sentinel-1 SAR data as primary input. A better potential can be developing such processing pipelines through AWS and web-applications, which need to be investigated in this current project.

Joint estimation of crop biophysical parameters will be ingested in crop yield forecasts, which could be explained in a better way with a combination of these descriptors instead of an individual growth parameter. It is also essential for operational crop parameter retrieval from EO data where it is desirable to estimate crop parameters jointly. It is because models using single outputs take a longer time to train separately and are computationally expensive. Moreover, the joint estimation of crop biophysical parameters has importance due to their underlying relationships and incoherent variations. In recent results reported in [16] for joint estimation of crop biophysical parameters from SAR data with promising accuracies are very interesting. In this proposed work, the multi-target regression technique will be utilized for the joint estimate of the biophysical parameter (viz. PAI and biomass) by inverting the calibrated WCM. Furthermore, a robust validation scheme with different test sites (in India as well as the host institution in Spain) will be carried out by collaborations. To transition from scientific applications to operational monitoring, the current methodology of WCM inversion needs to be investigated for various crop types so that it can be applied for a broader range of cropping systems. Both these components will be developed under AWS cloud framework and processing pipelines.

5. Cloud computing and Earth observation requirements

5.1. EO-data:

- Sentinel-1 and Sentinel-2 data through European Copernicus programme

Data frame rate=approx. 7.6 GB per scene of Sentinel-1; So, for a 6-day revisit it would raise up to 200 GB for a crop season. Hence, processing such computation intensive data justifies the utilization of a cloud processing chain.

- RADARSAT-2 data through JECAM SAR Inter Comparison Experiment activity

5.2. Cloud computing requirements:

The data rates of existing systems are quite high. A monthly computing expenses of requirement is shown in Table 1. For, 3 years of project the requirement is approx. **$72000**.

Table 1. Monthly computing requirements

Service Type	Components	Region	Component Price	Service Price
Amazon EC2 Service (Asia Pacific (Mumbai))				$1,601.75
	Compute:	Asia Pacific (Mumbai)	$262.35	
	EBS Volumes:	Asia Pacific (Mumbai)	$1,167.40	
	EBS IOPS:	Asia Pacific (Mumbai)	$0	
	Inter-Region Data Transfer Out	Asia Pacific (Mumbai)	$172	
AWS Data Transfer In				$0
	Asia Pacific (Mumbai) Region:	Global	$0	
AWS Data Transfer Out				$218.50
	Asia Pacific (Mumbai) Region:	Global	$218.50	
AWS Support (Business)				$181.53
	Support for all AWS services:		$181.53	
		Free Tier Discount:		($4.95)
		Total Monthly Payment:		$1,996.83

(https://calculator.s3.amazonaws.com/index.html#r=BOM&s=EC2&key=calc-88972904-5D8A-4075-B3B7-C2422D37D172)

6. Description of deliverables/applications

The deliverables of the proposed project are crop inventory maps. It will include several analysis ready data (ARD) for end users of agriculture and the EO community.

Biophysical parameter maps capture the spatial variability among the crop fields over the entire growing season. These maps would enable continuous monitoring at large spatial scales throughout the season, thereby supporting yield forecasting and productivity monitoring. Furthermore, this type of cloud-based framework for SAR data provides insights into potential prototypes for handling the high volumes of data, as expected from future operational SAR missions. Such an approach could significantly advance the operational use of SAR for agricultural monitoring.

7. Timeline

	2019	2019	2019-20	2020	2020	2020	2020-21	2021	2021	2021	2021-22	2022
	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-May	Jun-Aug	Sep-Nov	Dec-Feb	Mar-Apr
AWS-Hands on/Training	■											
In-situ measurement Plan	■											
In-situ Measurements		■	■	■	■	■	■	■	■	■		
Development of model framework			■	■	■	■						
Testing and validation					■	■	■	■	■	■		
Peer reviewed publications and Report					■	■			■		■	■

Reference:

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