Space Based Data Usage for Smart Farming

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Abstract. Precision Agriculture and input optimization with knowledge sharing are key for smart farming. The use of new technologies such as satellites, drones, navigation, AI/ML, big data, IoT, cloud-computing makes farming and agriculture smarter and transparent. Use of such advanced technologies, governmental officers and farmers can create evidence-based prescription maps for variable rate application of inputs, such as fertilizers, pesticides, and irrigation. Also, smart farming improve efficiency, reduce costs, simplify forecasting, streamline recording and reporting, and boost the sustainability and environmentally friendly agriculture while addressing todays needs and helping future planning. This paper is a brief overview of space-based tools that are currently available for smart farming and also importance of earth observation for smart farming with some examples on rice crop in Asia.

1 Smart Farmimg

1.1 History of Smart Farming

Smart farming, also known as precision agriculture, involves the use of modern technologies and data-driven approaches to improve production efficiency, reduce production cost, simplify forecasting, streamline recording and reporting, and boost the sustainability and environmentally friendly agriculture. The current data and information driven agricultural technology has been evolved since the civilization of mankind. More than 10,000 years ago, agriculture with first commercial fields was deployed using manual or animal drawn operations. From 18th Century, industrial revolution had been occurred and the concept of smart farming has gained significant traction. The agricultural industry witnessed the advent of mechanization. The introduction of machines such as the seed drill, mechanical reaper, and threshing machines revolutionized farming practices and increased efficiency. In 1940 an American scientist started to experiment disease resistance high-yield varieties of wheat in Mexico and it was a great success. This success was soon spread worldwide in 1960s adopting many of these techniques to increase production through introduction of high yield seeds, soil fertilizer, pesticides. This new era was named as "Green Revolution". These innovations were combined with the establishment of agricultural research institutions and investments on agriculture research by governments. The Green Revolution had a significant impact on global food production. It helped increase the crop yields, particularly for staple food crops such as wheat, rice, and maize, which played a crucial role in alleviating food shortages and reducing famine in several countries. The introduction of high yield crop varieties and improved farming practices also led to increased farm incomes and improved living standards for many farmers. However, the Green Revolution also had negative impact on agricultural practices, and environmental and social environment too including human health issues. For instance, the heavy reliance on synthetic fertilizers and pesticides led to increased chemical pollution of soils and water bodies and the focus on a few high-yielding varieties led to a loss of agricultural biodiversity and the displacement of traditional crop varieties.

Starting with the launch of earth observation satellites in 1960s, and the development of remote sensing technologies, it became possible to gather valuable information about crops and soil conditions remotely (from a distance). Remote sensing techniques allowed farmers to monitor planting information and crop growth condition. From 1980s-1990s, by the integration of Global Positioning System (GPS) technology with GIS, agriculture entered a new era referred to as Smart Farming. GPS-enabled Agriculture machinery and farm devices provided accurate location data, allowing farmers to precisely navigate fields and target specific areas for proactive interventions such as irrigation, fertilization, and pesticide application. This led to the emergence of precision farming techniques, which aimed to improve yield by maximizing resource utilization and minimizing the wastage and addressing labour shortage.

From 2000s onwards, we entered the "Digital Agriculture" age using Internet of Things (IoT) and GIS as well as remote sensing data. The development of low-cost sensors and the rise of the Internet of Things (IoT) and Artificial Intelligence and Machine Learning further expanded the capabilities of smart farming. Sensors place in the field to collect real-time data on various parameters such as temperature, humidity, soil moisture, and crop condition. This data sends to cloud based or

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tailor-made systems for analysis, visualizations, sharing via IoT. Once they combine with advanced analytics and machine learning algorithms, farmers able to make data-driven decisions and implement appropriate and precise interventions. In other word, the increasing availability of large-scale and big volume of agricultural related data including remote sensing data, IoT base field data has enabled new avenues for smart farming. Farmers can now leverage big data analytics to gain insights of trends, predict yield, optimize resource allocation, and monitor and manage farm operations more efficiently. Overall, smart farming has evolved over time, incorporating various technologies such as earth observation, precise positing, IOT and artificial Intelligence and/or machine learning, and data-driven approaches to enhance agricultural practices. Its history reflects a continuous effort to leverage technology for increased productivity, sustainability, resource efficiency and eco-friendly agriculture.

1.2 Value of Earth Observation Data for Smart Farming

The use of Earth observation satellite data in smart agriculture brings several advantageous and benefits to the industry. Earth observation satellite data assists modern agriculture industry in number of ways through their remotely observed data in implementing precision agriculture techniques. By analysing multispectral or hyperspectral images captured by satellites, farmers can identify spatial variability of the status of crops and some phenological and soil properties of their fields. This information helps optimizing interventions, such as seeding, fertilizing, and pest/weed controlling, by targeting specific areas that require attention. Precision agriculture enhances the efficiency of the use of resource, reduces costs, and could minimizes environmental impacts.

Earth observation satellites also provide real-time and near-real-time weather and climate data. By integrating satellite-derived weather information with on-ground sensors, farmers can access accurate and localized weather forecasts. This helps them planning their agricultural activities, optimize irrigation scheduling, and mitigate risks associated with extreme weather events. Satellite data also aids in monitoring and mitigating natural disasters, such as droughts, floods, and wildfires, by providing timely information for early warning systems and emergency response planning.

Finally, integrating satellite data with advanced analytics and machine learning techniques allows the development of decision support systems for farmers. These systems provide actionable insights, predictive models, and recommendations based on satellite imagery and other relevant data sources. They help farmers make data-driven and evidence-based decisions, optimize resource allocation, and improve overall farm management practices.

Overall, the value and purpose of using Earth observation satellite data in smart agriculture lie in its ability to provide timely, accurate, and actionable information for farmers. By harnessing satellite technology, farmers can optimize their operations, increase productivity, minimize environmental impacts, and contribute to sustainable agricultural practices.

1.3 GIS with Earth Observation Data and IoT for Smart Farming

IoT (Internet of Thinking) and drones and earth observation data are integral components of smart farming, facilitating data collection, monitoring, and analysis on the geographic information system (GIS). These technologies enable precision agriculture, enhance resource management, improve crop health, and support decision-making processes. By harnessing the power of IoT and drones with earth observation data on GIS, farmers can achieve higher efficiency, sustainability, and profitability in their agricultural operations.

For data collection and monitoring, IoT devices, such as sensors and monitoring systems, are deployed throughout the farm to collect real-time data on various parameters like soil moisture, temperature, humidity, and crop health with satellite-based information. This data is crucial for understanding field conditions, identifying potential issues, and making informed decisions. Drones equipped with sensors and cameras can also provide high-resolution imagery and aerial data, enabling comprehensive field monitoring and analysis assisting sustainable agricultural management. IoT data with high temporal and hight resolution data are complementary to wide area earth observation satellite data.

The linkage between GIS, IoT and earth observation data is highly important for smart farming. It enables farmers to leverage spatial information and satellite imagery to gain valuable insights and make informed decisions in agricultural practices. Here are some key reasons why the linkage between GIS and earth observation data is crucial for smart farming. By overlaying satellite imagery onto GIS platforms, farmers can generate detailed maps that provide valuable information about land characteristics, crop distribution, soil types, and other spatial features. This spatial analysis helps in understanding the variability within fields, optimizing resource allocation, and planning precision agriculture practices. By integrating this data with GIS, farmers can also map and monitor crop performance, identify areas of concern, and take targeted management actions. This helps optimize irrigation, fertilization, pest control, and other agronomic practices.

Risk management is another important aspect that need to be evaluated for maintain agriculture sustainability as well as quantifying risks on the environment due to agricultural practices. Incorporating satellite imagery depicting land cover, vegetation indices, and environmental conditions into GIS models, farmers can evaluate the impact of farming practices on the environment. Also, it is possible to assess soil erosion risks, biodiversity hotspots, and areas requiring conservation efforts through GIS modelling and analysis. This information aids in sustainable land management and ensures compliance with environmental regulations. Since there are more than 40 years earth observation satellite data record as of now, by incorporating historical satellite imagery, weather data, and other spatial information into GIS models, farmers can analyse patterns and trends. This helps in predicting and mitigating risks associated with weather events, diseases, pests, and crop failure. Decision support systems utilizing GIS and earth observation data provide farmers with actionable insights and recommendations for effective risk management.

For precision Agriculture and input optimization, farmers can create prescription maps for variable rate application of inputs, such as fertilizers, pesticides, and water. This targeted approach optimizes resource usage, reduces costs, and minimizes environmental impacts.

2 JAXA Earth Observation for Agriculture

2.1 Overview of JAXA Earth observation mission for agriculture

JAXA has developed and launched several Earth observations satellites that contribute to assessment and monitoring agriculture activities. Some of the JAXA Earth observation satellites and their roles in supporting agriculture are shown in Figure 1.

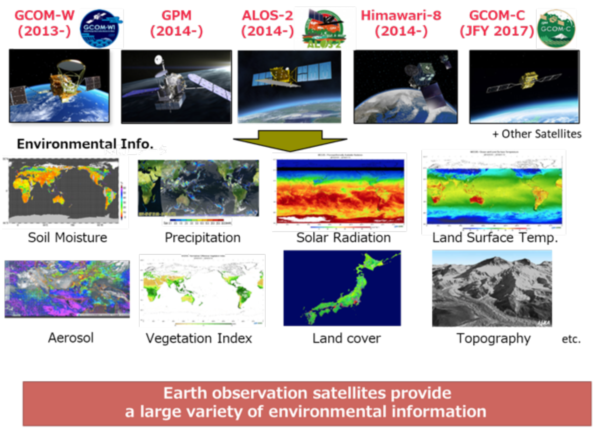

Figure1 Earth observation data for agriculture

GCOM-W (Global Change Observation Mission - Water) is part of the GCOM series focuses on observing water-related parameters. It provides data on soil moisture, snow cover, and vegetation health. This information is crucial for understanding water availability in agricultural areas, optimizing irrigation practices, and predicting crop yields. GCOM-C (Global Change Observation Mission – Climate) is a series of Earth observation satellites developed by JAXA. While GCOM-C is primarily designed for climate-related observations, its data can still be valuable in identifying status of land and assessing agricultural parameters such as land cover, vegetation health, and chlorophyll content. These measurements are crucial for monitoring crop growth, identifying areas of stress, and assessing the overall health of agricultural fields and in the end forecasting the crop yield.

ALOS (Advanced Land Observing Satellite): While not exclusively a satellite launched for agricultural use, ALOS plays a significant role in monitoring land and vegetation. Its data can be used to assess land cover changes, monitor crop health, and track deforestation and reforestation efforts, all of which are relevant to agriculture. The Japanese geostationary meteorological satellite named Himawari series, operated by the Japan Meteorological Agency (JMA), provide real-time imagery of weather patterns. This information is valuable for monitoring weather conditions such as rainfall, cloud cover, and temperature that are crucial for agricultural activities.

Soil moisture by GCOM-W and ALOS-2 are valuable for optimizing irrigation strategies, preventing waterlogging or drought stress, and improving water use efficiency in agriculture. Crop phenology by GCOM-C NDVI and ALOS-2 SAR backscattering aids in predicting planting and harvesting times, assessing crop development, and identifying anomalies that might affect yields. GSMaP has multi-satellite global precipitation map under the Global Precipitation Measurement (GPM) Mission, by using Dual-frequency Precipitation Radar (DPR) onboard GPM core satellites, other GPM constellation satellites including GCOM-W, and Geostationary satellites including Himawari. This precipitation information by GSMaP has been widely used for scientific purposes as well as for monitoring agricultural activities. On set of drought and flood as well as possible recovery time span derived from GSMaP are useful for agriculture. Timely agrometeorological information of such devastating events is crucial for implementing mitigation measures and protecting crops. In order to contribute to food security issue, Ministry of Agriculture, Forestry and Fisheries, Japan provides agrometeorological information for major commodities using satellite data with technical support from JAXA.

2.2 Land observing -ALOS

Rice is the main commodity crop in Asia. It is a staple food for a significant portion of the population in many Asian countries and holds immense cultural and economic importance. Asia is often referred to as the "Rice Bowl of the World" due to its dominant role in global rice production and consumption. Rice is not only a primary source of nutrition but also a key component of the agricultural economies of countries across the Asian continent. It is grown in a wide range of agroecological environments, from lowland paddies to upland fields and even in flood-prone areas. The methods of cultivation vary, but rice remains a central crop in the region, supporting livelihoods and economies. In many Asian countries, including major rice producers like India, China, Indonesia, and Thailand, the main rice crop season typically divided into two primary seasons: "wet/rainy" season and "dry" season. Wet/Rainy season is the main rice growing season that coincides with the monsoon rains. The availability of water from monsoon rains allows the cultivation of rice in flooded fields. This is the season when most of the rain-fed rice is planted and harvested.

Dry season follows the wet/rainy season, and this season is characterized by lower rainfall and may require irrigation for rice cultivation. In some regions, varieties of rice that are better adapted to drier conditions are grown during this season.

Given the dynamic of rice cultivation, extensive area coverage, dependency of weather patterns, satellite remote sensing can assist in many ways to monitor and assess status of a rice crop lands. Specifically, synthetic aperture data (SAR) is indispensable to monitor paddy field because SAR data can be used in all weather conditions given the persisting cloud cover during monsoon season.

ALOS-2 with the Phased Array type L-band SAR-2 (PALSAR-2), shown in Figure 2, was launched in 2014 and has been in operation until today. PALSAR-2 has a Spotlight mode (1 to 3 m) and a high resolution (Stripmap) mode (3 to 10 meter), while PALSAR has a 10-meter resolution. PALSAR-2 achieved the highest resolution of L-band radar by implementing 3-meter resolution using Stripmap mode while keeping wide observation swath.

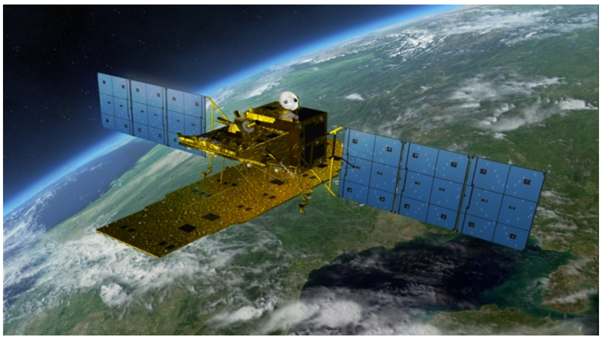

Figure 2. ALOS-2

The value of L-band Synthetic Aperture Radar (SAR) lies in its unique characteristics that make it suitable for various applications, particularly in remote sensing and Earth observation. L-band SAR operates at a wavelength of around 1 to 2 GHz, which falls within the microwave range. Especially, L-band SAR can penetrate through vegetation and soil to a certain extent due to its longer wavelength compared to higher-frequency microwave bands like C-band or X-band. This penetration capability allows L-band SAR to provide information about the subsurface conditions, making it useful for applications like soil moisture estimation and mapping of root zone characteristics. It can also be used to estimate forest biomass, monitor deforestation, track agricultural crop growth, and assess soil moisture levels.

ALOS-4 is a satellite to observe the Earth's surface using its onboard phased array type L-band synthetic aperture radar (PALSAR-3). The L-band radar technology has continuously been developed in Japan. With further improved observation performance compared to the predecessor PALSAR-2 aboard the ALOS-2 are developing the satellite aiming at achieving both high resolution and a broader observation swath. Unlike observations by an optical sensor, radar images can be acquired day and night as it does not require sunlight. Moreover, since radio waves can penetrate cloud, the images can be obtained regardless of weather condition. The ALOS-4 will leverage these merits for observing and monitoring disaster-hit areas, forests, and sea ice. In addition, it will also challenge new areas such as monitoring infrastructure displacement.

3 Overview of Rice Crop Monitoring Service in Asia

3.1 Asia Rice in GEO GEOGLAM

GEOGLAM Asia Rice is a specific initiative that falls under the Global Agricultural Monitoring (GEOGLAM) under G20 declaration that aims to enhance the use of satellite and Earth observation data to monitor and provide information about agricultural production around the world. Especially, with the cooperation of FAO Agriculture Market Information System (AMIS), it contributes to food security and supports decision-making in agriculture.

The specific focus of GEOGLAM Asia Rice is to monitor rice production in the Asian region using satellite observations and remote sensing technologies. This initiative recognizes the importance of rice as a staple food in many Asian countries and aims to provide timely and accurate information to enhance rice production, manage risks, and improve food security. The main objectives of GEOGLAM Asia Rice are; rice crop monitoring, yield estimation, early warning, damage assessment, advanced research cooperation and knowledge sharing and outreach to satellite data usage for agriculture decision making support.

Under timely monitoring, rice crop outlook information is compiled to provide high accurate, transparent and up-to-date information on rice crop conditions, including planting, growth, and health, throughout the growing season. Yield estimation is to estimate rice yields in different regions using satellite data and modelling techniques. Rice crop outlook could further assist early warning and damage assessment to identify potential or ongoing issues such as droughts, floods, or pest outbreaks that could impact rice production, allowing early response and mitigation.

In addition, Asia Rice activity promotes not only data and derived information sharing but also knowledge sharing through workshop such as Asia Ocean GEO symposium and training in cooperation with space agencies and agriculture related government organizations in Asia.

3.2 ARSAF SAFE

The Asia-Pacific Regional Space Agency Forum (APRSAF) is an international forum that facilitates cooperation and collaboration among space agencies, public and private organizations, and experts from academia and research organizations in the Asia-Pacific region. Its goal is to promote peaceful and safe use of space technology and applications for socioeconomic development and environmental protection.

Space applications for the environment (SAFE) initiative launched in the Space Application Working Group of APRSAF addresses the use of space technology and satellite-based systems to monitor, understand, and manage various aspects of Earth's environment. These applications play a crucial role in gathering data, providing insights, and aiding decision-making processes related to environmental management, conservation, and sustainable development. As of March 2020, there have been 27 prototyping activities completed under the SAFE initiative. These prototyping efforts involve testing and developing various methodologies and technologies to address specific environmental or agricultural challenges. Since 2020, the implementing structure of SAFE was changed from a bilateral approach to a "multilateral" approach. This change allows more extensive collaboration with space agencies, research institutions, and international organizations within the Asia-Pacific region. Since then, three SAFE projects were launched including *agromet*, *rice crop monitoring* and *CH4Rice*.

The objective of Agromet project initiated in 2018 was to develop a mechanism and system for sharing agrometeorological information. This information is aimed at improving agriculture information services across the region, thereby enhancing agricultural planning and management. Second project is the rice crop monitoring project started in 2018. This project was designed to assist the region in monitoring food security status by using space-based data and technology to monitor rice crops. The newest project is CH4Rice project started in 2022. This CH4Rice project is designed to monitor water level in paddy field to reduce CH4 (Methane) emission from paddy field optimizing water level during growing season. Figure 3 shows a summary of all the above three projects conducted under APRSAF SAFE.

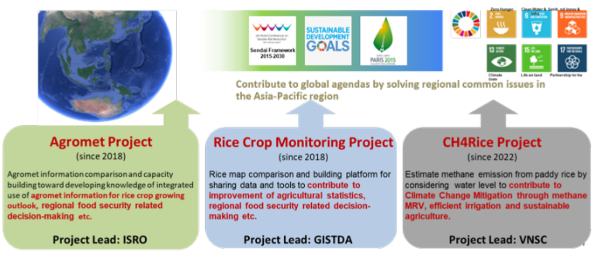

Figure 3 APRSAF SAFE projects for agriculture

3.3 INAHOR

A software package named International Asian Harvest mOnitoring system for Rice (INAHOR) was developed to estimate rice planted area using SAR data. This package uses data from L-band SAR of ALOS-2 acquired over an area for two or more time periods. During the monsoon when many Asian counties cultivate their major paddy crop, those areas are often covered with heavy cloud limiting the use of optical sensor data. However, the wavelength that uses on SAR sensors can penetrate the cloud allowing SAR sensors to monitor paddy fields regardless of the presence of cloud. Therefore, this software package was developed to address the needs in Asia with the collaboration of Asian space agencies and agriculture organizations under APRSAF SAFE. Also, this effort was supported by the Asian Development Bank and number of private companies. INAHOR was introduced and training assistance was provided in number of Asian countries to collect agricultural statistics data much effectively under APRSAF SAFE and GEO Asia Rice team activity for rice crop monitoring.

INAHOR uses ALOS-2 data and administrative boundary data provided in GIS format as inputs. The estimates of rice crop area for each administrative district is calculated and exports as a CSV file, and a Validation Sheet (jpg file format) with a Landsat image of the administrative district. In INAHOR, median filtering of ALOS-2 data is used for noise reduction and machine learning is used for classification. In order to promote easy and efficient usage of INAHOR, the software is installed and available for users on cloud-based systems such as Google Earth Engine. The concept of INAHOR is shown in Figure 4.

Figure 5 shows the result of Vietnam rice crop area estimation in state / provincial level. In most of provinces, INAHOR results are well matched with ground based statistical information of the country. Where there are discrepancies in ground based and satellite derived results, agriculture organizations were requested to explore the reasons for such disparity. Although there are some discrepancies, satellite estimations are very useful to improve national agricultural statistics. Further, INAHOR outcome is useful for smart farming such as advising planting period, fertilizing timing, water management, and pest management.

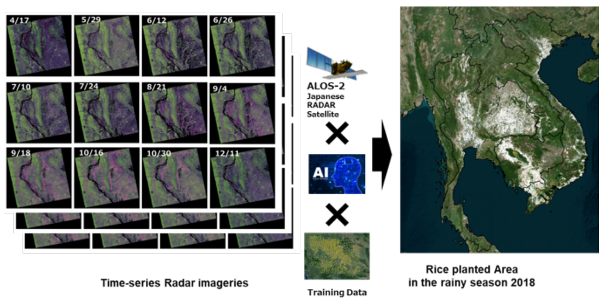

Figure 4 INAHOR concept

Figure 5 Vietnam result by INAHOR on GEE

INAHOR uses random forest algorithm as the machine learning technique. It is indispensable to collect training data on the ground for assist the train algorithm of the classification. During the ASEAN Food Security Information System (AFSIS) training activity using INAHOR on GEE platform, over 3000 points (rice and non-rice crop field) were collected as training data. This is a labour intensive and costly activity as field visits and other information such as optical satellite data and map information are required to identify paddy/non-paddy training points. Therefore, with the cooperation of supportive agriculture machinery companies, an automatic training data collection system was introduced to make the training data collection activity efficient.

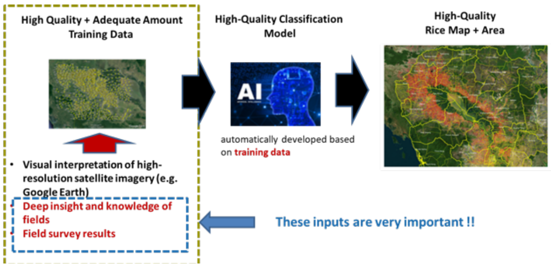

Figure 6 Training data for INAHOR

Overall, INAHOR with ALOS-2 showcases the power of space technology and remote sensing in addressing real-world challenges, such as accurate agricultural area monitoring. By using SAR data to estimate paddy rice planting areas, even in cloudy conditions, the system can provide valuable insights to support food security, resource allocation, and sustainable agricultural practices.

3.4 JASMAI

In 2021, JAXA and the Ministry of Agriculture, Forestry and Fisheries collaborated to promote the use of earth observation satellite data in the field of agriculture, forestry and fisheries by establishing the Japan Satellite Monitoring System for Agrometeorological Information (JASMAI). JASMAI utilizes JAXA's research and development results of a system that enables users to view agricultural weather data (temperature, precipitation, humidity, solar radiation, wind patterns, and soil moisture) and crop growth conditions (vegetation index) on the web in near-real time. These factors are crucial for understanding the climatic conditions that impact crop growth and the crop health. JASMAI utilizes satellite observation data from JAXA, Japan Meteorological Agency, NASA, and number of other countries to provide information on the growth of main production zones of major cereals and other crops, specifically in Asia in the form of maps and graphs.

JASMAI provides users with easy-to-understand visualizations and tools to interpret the data. Farmers, researchers, and policymakers can access these platforms to make use of the data to derive necessary information to make decisions about irrigation needs, planting strategies, harvesting time, and pest management plans etc. JASMAI can also offer data specific to different regions and areas, helping farmers make decisions tailored to their local conditions. In addition, JASMAI's historical data can help in identifying trends, making predictions about climate patterns, and adapting farming practices to changing conditions.

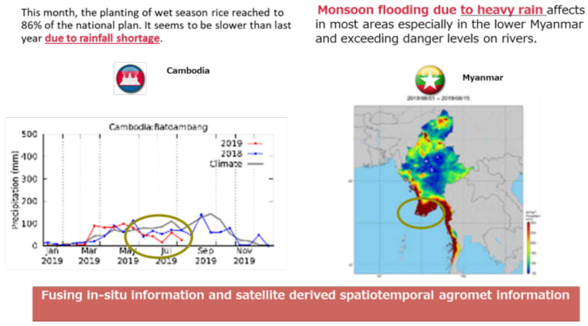

Figure 7 Agromet information for rice crop outlook using JASMAI/JASMIN in ASEAN

The rice crop outlook is a good example of the use of JASMAI. It can be used before planting seasons to guide farmers in making decisions about inputs, cultivation practices, and potential risks. Governments and organizations involved in agriculture often provide guidance based on these outlooks to support informed decision-making and mitigate potential challenges.

Also, JASMAI enhances agricultural resilience by providing timely and accurate information to manage risks associated with weather variability and climate change. It aids in optimizing resource use, increasing productivity, and contributing to sustainable agricultural practices.

4 Conclusion

Precision Agriculture and optimization of farmland in puts using earth observation data, IoT, GIS and AI/ML technologies, farmers can create strategic plans and evidence-based maps for variable rate application of inputs, such as fertilizers, pesticides, and water. This targeted approach optimizes resource usage, reduces costs, and minimizes environmental impacts. At present, earth observation satellite community provides enormous amount of time series data and derived information on certain agroclimatic parameters and land parameters for the possible use in agriculture. JAXA JASMAI and COPERUNICS by EU/ESA are good examples that demonstrates the provisions of space-based technologies. However, for individual farmer, the spatial resolution of those open and free data provided by the satellite communities are not sufficiently enough.

Therefore, for individual needs, farmers may have to turn to commercial providers or for ground-based observations including drone to monitor their individual fields. Furthermore, reasonable price of IT / GIS platform with data analysis system are also a hurdle in Asia because of cost and limited IT expert resources / skill to interpret earth observation information. With the current global commitments, it is expected that more and more high-resolution satellite data become available with improved spatial and temporal resolutions, and it is anticipated that the strengthened involvement of the commercial sector in reaching individual crop land for constructive and productive smart farming.

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