Final Report – July 2022

VietSCO Phase 1
(July 2020 – July 2022)

Version 1.0

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Signature from Stéphane MERMOZ, GlobEO, on 29th September 2022:

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1. Objectives and Purpose of VietSCO Phase 1

Vietnam is one of the countries most exposed to extreme events linked to climate change (Adger, 1999; Yusuf and Francisco, 2009). Although it has always been affected by heavy rains causing floods, recent years have seen an increase in the frequency of extreme climatic events of the typhoon type, generating human losses and significant damage. During these catastrophic events, Earth Observation-based emergency response mechanisms supply civil protection with mapping in "emergency response" mode but cease to operate after the initial humanitarian response phase of about a week. The post-crisis period is fundamental for a rapid and efficient economic recovery. In 2017, a report from the Central Committee for Natural Disaster Prevention and Control for Vietnam raised several questions concerning control and reconstruction following natural disasters, as well as prevention. In particular, it underlined the need for reconstruction which both emits less greenhouse gases and offers increased resilience to reduce the impact of similar events.

The project aims to provide operational tools for the dynamic monitoring of rice cultivation in the Mekong Delta as well as to monitor the impact of typhoons on agricultural areas in all of Vietnam in support of more resilient agricultural planning. In recent years, the region has been strongly affected by climate change. The frequency, duration, and increased intensity of droughts, floods, and salt intrusion pose a rising threat to domestic rice production in Vietnam. In 2016, for example, the production of spring rice in the Mekong Delta was reduced by 17%, following a drought intensified by the El Niño phenomenon. Faced with these inevitable climate changes, the Vietnamese Ministries of Agriculture (Ministry of Agriculture and Rural Development- MARD) and of the Environment (Ministry of Natural Resources and Environment- MONRE) have to balance short-term management and long-term rice production. Decision-making is currently based on data collected in situ at the local level (villages, provinces ...) and assembled in a database of national statistics (General Statistics Office).
The VIMESCO-Rice component of VietSCO would enable regular monitoring of rice fields via Earth Observation (EO) satellites. Regular radar remote sensing data interpreted using dedicated methods and algorithms will generate mapping information that supplements in situ data and statistics (area planted, state of development, cropping calendar, productivity indicators, number of harvests per year).

The ARRO Vietnam component of the project proposes to set up a full-scale demonstrator of an "agriculture resilient recovery observatory" largely produced through satellite observations, which can be triggered by the government (local or national) and international development aid organizations after a major disaster occurs. The use of Earth Observation data, covering the entire affected area, acquired throughout the process of returning to normal and making it possible to monitor the actual progress in the affected area, contributes to creating the most resilient reconstruction possible. This type of observatory would support spatial agricultural planning policies, in order to move in the long term towards reconstruction adapted to the expected impacts of climate change.

Interactions between the project components will reinforce the synergy between climate change scenarios and socio-economic impacts of the typhoons analyzed. The ARRO will be able to provide the VietSCO project with an impact of extreme events component which will be useful for modeling, while VIMESCO-Rice will supply the ARRO component with slow onset effects in order to steer reconstruction priorities and decisions.

The project principally uses satellite data, mainly open and free Sentinel-1 radar data, particularly suitable for tropical areas with high cloud cover. The ARRO component may also use other sensors to validate S1 data and to increase frequency and timeliness of revisits.

1.1 Objectives and Purpose

VietSCO, the Vietnam Space Climate Observatory, has two central components:

- Monitoring rice production areas affected by climate change in the Mekong Delta;
- Monitoring impact of typhoons on agricultural areas in Vietnam in support of more resilient agricultural planning.

The VIMESCO-Rice component will in the long-term enable regular monitoring of rice fields via Earth Observation (EO) satellites. Regular radar remote sensing data interpreted using dedicated methods and algorithms will generate mapping information that supplements in situ data and statistics (area planted, state of development, cropping calendar, productivity indicators, number of annual harvests, salinity intrusion, year over year changes). The main envisaged users for VIMESCO-Rice are MARD CIS and MONRE, although provincial authorities may also be interested.

The Viet-ARRO (Agricultural Resilient Recovery Observatory) component of the project set up a full-scale demonstrator of a "resilient recovery observatory" largely produced through satellite observations, which can be triggered by the government (local or national) and international development aid organizations as soon as a major disaster occurs. The main user for Viet-ARRO is VNDMA.

After completing Phase 1, which aims to validate the methodologies and usefulness of products with users, Phase 2 will complete the transfer to Vietnamese users and consider extending to new thematic areas.

1.2 Genesis and partners

Background and Objectives

VietSCO, the Vietnam Space Climate Observatory project, began in July 2020 and was completed in July 2022. It has two central components:

- Monitoring rice production areas affected by climate change in the Mekong Delta (VIMESCO Rice).
- Monitoring impact of typhoons on agricultural areas in Vietnam in support of more resilient agricultural planning (Viet-ARRO).

The use of Earth Observatory/EO data and derived products allows users to understand changes in rice production areas and impacts of extreme weather events over time and contributes to resilient reconstruction and recovery. After extreme hydrometeorological events affecting agricultural production (mainly rice cultivation), the Viet-ARRO Demonstrator will provide key stakeholders at the local and national level with regularly updated geospatial information, derived from satellite EO.

VietSCO Products

The products developed for the VietSCO project (including both VIMESCO Rice and Viet-ARRO) are listed in the User Requirements Document (URD):

VM-Rice SR Map: Seasonal Rice maps
V-ARRO FE Map: Flood Extent map –flood extent and % district affected based on S-1
V-ARRO RR Map: Rice Recovery maps at S-1 acquisition date
V-ARRO FD Map: Flood Duration map – extent of flood over time based on S-1
V-ARRO RAF Map: Rice crop Affected by Flood map – areas planted with rice affected
VM-Rice RGS Map: Regional Growth Stage map
VM-Rice CC Map: Crop Calendar map
VM-Rice CCC Map: Crop Calendar Change map
VM-Rice ACR Map: Annual Change Rice map – areas changed to or from rice year over year
VM-Rice DR Map: Drought/Rice map – areas affected by drought + rice areas (annual, year over year)
VM-Rice SI Map: Salinity Intrusion map – impact of salinity intrusion (+ projections) on rice crops area
VM-Rice CCI Map: Climate Change Impact map – cumulative impact of climate factors

MARD CIS

Provision of monthly rice maps to MARD CIS offers a graphic representation of rice production changes over time and current status of rice growth. This source of information is in complement to existing ground-based sources and provides a method of verifying statistics independently.

MONRE

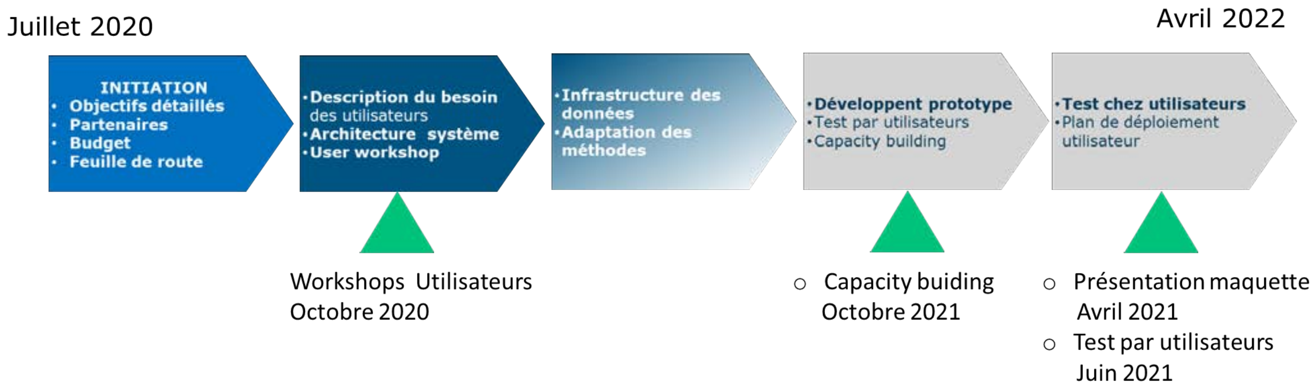
Availability of rice information in an easily displayed graphic format allows for easy understanding of climate change impacts on rice production; comparison with projections for salinity intrusion and drought allows for improved planning of rice production given climate change impacts. Capacity building relating to product generation (see list above) will be available.

VNDMA

Access to high resolution Copernicus Rapid Mapping and Risk and Recovery products. Training on how to activate these services and products. VNDMA will also receive additional training on how to use EO-based products for preparedness, response and recovery, and related capacity building training may also be arranged. Capacity building relating to product generation (see list above) will be available. The Viet-ARRO products will be disseminated through the VNDMA's National Disaster Information System. The Viet-ARRO will provide VNDMA with free and open access to data and information useful for assessing impact, planning, and monitoring recovery, and will serve as a forum for exchange and collaboration on recovery related issues to foster resilience at the community level.

VAST

Reinforcement of capacity within VNSC. Development of Vietnam Data Cube (including five years of Sentinel-1 data) and related applications. Capacity building relating to product generation (see list above) will be available.



2. Interactions with users

2.1 The VietSCO User Community

The main user community is divided along the main applications of the VietSCO project – one element focussed on rice cultivation and its adaptation to climate change; one element focussed on recovery in the agricultural sector after typhoons, which are expected to be more powerful, more frequent, and less predictable as climate variability increases.

The main users of the VietSCO Phase 1 products are:

- MARD CIS – statistics office interested in monthly rice yields
- MONRE NRSD – remote sensing directorate responsible for climate related observations, including those relating to rice production
- VNDMA – disaster management agency responsible for the full cycle of DRM, including improved recovery and resilience

In addition to these core users, future users include academia, and research institutes active in climate research, including IMHEN. Many IMHEN researchers participated in the VNSC User Survey that fed into the work of the U&ST.

2.2 The User & Science Team (U&ST) and Bilateral discussions

The VietSCO project was challenged by the inability to travel to Vietnam for the technical partners, due to CoVID restrictions. However, an User & Science Team was created and held two meetings. This group was instrumental in determining what requirements Phase 1 would have and what products would be generated.

The members of the U&ST are:
MARD, Vietnam National Disaster Management Agency (VNDMA);
MARD, Centre for Informatics and Statistics (CIS);
MONRE, Institute of Meteorology, Hydrology and Climate Change (IMHEN);

MONRE, Department of Climate Change National Remote Sensing Center (RSC);
VAST, University of Science and Technology of Hanoi (USTH);
VAST, Institute of Environmental Technology (IET).

The U&ST developed a Preliminary Statement of User Requirements (PSUR), which once reviewed and validated became the User Requirements Document (URD). The PSUR aimed to identify the users of VietSCO products and outputs, as well as the mandates of these users, and the systems they currently use. VietSCO products aim to integrate into existing systems and complement existing products. After developing the PSUR, through discussion of the User & Science Team, the identified needs were consolidated and matched to project outputs and a User Requirements Document (URD) was drafted. The PSUR identifies the broadest possible needs from the user community, while the URD consolidates this list and identifies the needs that the project aims to meet. Clearly, not all needs identified in the PSUR could be met by the URD. This process allows users to find a balance between desires and realistic budgeted products.

In addition to the U&ST work, bilateral meetings were held with VNDMA and NRSD (MONRE). At each meeting, the Vietnamese user group was able to present itself and its mandate and indicate their interest in VietSCO.

The main conclusions of the VNDMA meetings were:

- VietSCO presents many opportunities for collaboration.
- VNDMA has been more focused on response and is a user of Copernicus EMS; recovery requires a different approach.
- Understanding impacts on agriculture after events is important and could be a major product under the collaboration.

The current objectives of the VNDMA for enhancing applications of S&T are:

- Prioritize the application of S&T in monitoring, monitoring supervision, direction, administration, and response to natural disasters.
- Promote the application of remote sensing technology, informatics, automation, online monitoring, management, exploitation, forecasting, database transmission, and real-time response operation.
- Promote and apply new materials, new solutions to DRR and climate change.

The current priority within VNDMA is to reinforce prevention, especially early warning. VNDMA is working closely with JICA (Japan International Cooperation Agency, providing financial assistance to developing countries for socioeconomic development) on early warning systems. However, VNDMA has recognized a complementary need for recovery information, and the VietSCO-VietARRO project will provide data and satellite-based products to feed recovery information into the Vietnam Disaster Monitoring System (VDMS).
There is a clear desire to increase the use of satellite imagery and develop related capacity more generally. The main VNDMA objectives for VietSCO are:

- Improved satellite-based information on damage from typhoons and status of recovery (through improved Copernicus products integration).
- Indications of resilience in damaged areas (build back better).
- Impact on rice production from typhoons in the Mekong Delta.

VNDMA shares in the assessment that VietSCO tools are valuable. From a long-term point of view (resilience/recovery), VNDMA is interested in research on the stability of the coastline, to understand where and why coastal change is happening. The Southern Institute for Water Resources (part of MARD) has a strong department working on erosion and saline intrusion and should be brought into the project, as well as the Institute for Water Resources Planning (also MARD).

Existing products and dissemination systems:
The main system used now for dissemination of disaster information is the Vietnam Disaster Monitoring System (VDMS), still in a pilot phase. VNDMS is being developed by DMPTC under VNDMA. The VDMS includes a range of information from many sources:

- KTTV: hydromet states, hydropower and agricultural reservoirs.
- Satellite images.
- Bridge information.
- Losses and damage (socio-economic), infrastructure status, DRR plans.
- Field and community data.

The VDMS system also includes a built-in early warning component, linked to flood warnings, discharge of reservoirs (3 day and 7 day outlook). Evacuation plans when required are based on VDMS maps. VDMS can also provide maps of projected damage/affected areas for “possible” floods in the event of super storms.

There is a strong desire to maximize the use of real-time data in VDMS.
Some identified areas of interest for satellite information include:

- Monitor impacts along the coasts using satellites.
- Scope and scale of flooding over time.
- Capacity building relating to satellite imagery use.

The VDMS uses remote sensing images to assess the level of inundation caused by rain after storms, and to determine the speed of urban development to assess the likelihood of impacts from natural disasters. Currently VDMS has more than 1,000 satellite images of various kinds relating to events since 2007.

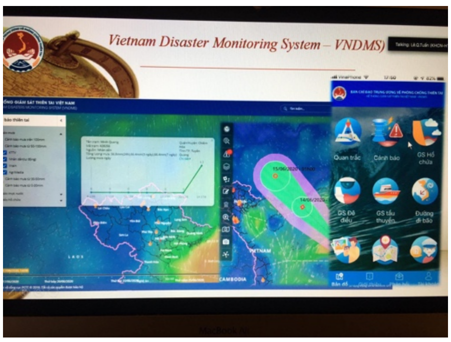


Figure 1. VDMS screenshot showing typhon information from weather satellites

In-situ and other data relevant to VietSCO:
Most of the data currently used in the VDMS is from non-satellite sources. These data are collected through local representatives in a national-wide bottom-up process. There is also a plan to increase use of cell phone data. Access to the VDMS would allow validation of certain experimental satellite products.

Specific types of non-satellite data identified in VDMS include:

- Reports (word, pdf).
- Maps of rapid assessments (pdf).
- Disaster risk maps (computer copies, mapinfo, shapefile).
- Disaster response process documents (tables, word files, pdf, database management software outputs).

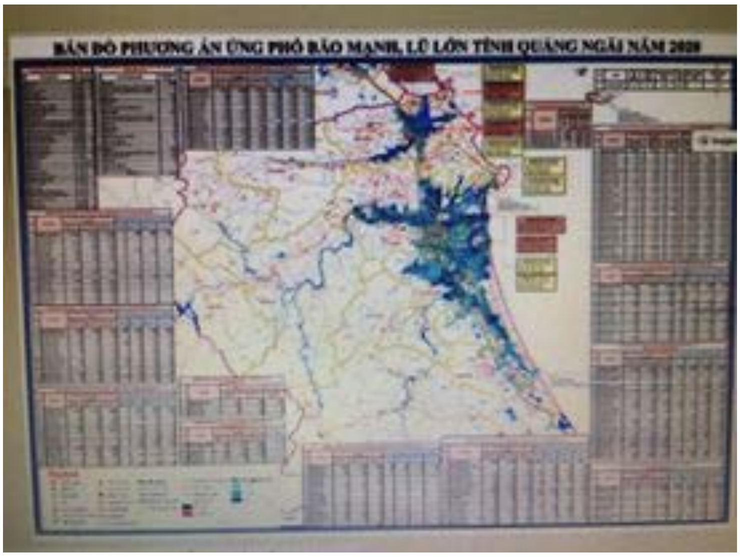


Figure 2. Flooding impact at district level, with map showing flood extent and tables with detailed impact.

NRSD

The main conclusions of the NRSD meetings were:

- Strong interest from NRSD in VietSCO;
- A desire to collaborate on validation of VietSCO products.
- Longer term interest in extending VietSCO to forestry (Phase 2) and to reinforce technology transfer and capacity building at NRSD.

Senior MONRE officials indicated there was a basis for solid collaboration between Vietnam and France in the framework of the project. NRSD has sent a PPT describing specific needs and collaboration proposals (see annex). Khanh presented the NRSD team and Linda presented the overall VietSCO project, its timeframe, and its objectives. She also indicated a new phase is currently being designed for post April 2022, and discussions should reflect both what can be achieved by April 2022, and what VietSCO should look like beyond that date.

NRSD presentation: Tung presented NRSD, an organization with some 244 employees, and a wide range of activities and capabilities. The NRSD also runs the National Remote Sensing Data Base which has over 300,000 scenes in it. This includes VNRedSAT-1, SPOT 6 and 7… They operate a ground station currently being upgraded to receive CSK data in partnership with Italy.

The main areas for collaboration were proposed by NRSD:

For Phase 1, NRSD proposes to VietSCO project side:

- VietSCO project provides the rice maps generated from S1 for validation (i.e., comparison with 2020 National Land inventory map). NRSD is interested also in Drought effect and Salinity intrusion maps.
- VietSCO to Supply software to build rice maps and Drought effect and Salinity intrusion maps
- Training and technology transfer for generating rice, DR and SI maps by remote sensing for NRSD's technicians. The time of organizing the training course will be done when the VietSCO project is ready.
- VietSCO project will prepare softwares, document and trainers.
- Implementation plan: Sept/2021 to Apr/2022.

NRSD will cooperate with Project Partners by comparing/validating the rice maps of 2019-2020 first in the Mekong Delta and the Red River Delta where the rice detection methods are operational:

- Using the 2020 National land inventory map for reference.
- Center of Nature Resources, Environment and Climate Change Monitoring will support validation of the rice maps in Northern area.
- Southern Center of Remote Sensing (in HCMC) will support validation of the rice maps in Southern area.
- NRSD will build a technician team (about 15-20 persons) to participate in the training courses and to receive the technology transferred by VietSCO project.
- Training course can be held online. NRSD will prepare the location and the computer for training course of NRSD side.
- Implementation plan: Sept/2021 to Apr/2022.

For Phase 2, NRSD proposes a focus on forest monitoring using remote sensing.

- France side will support software, document, image satellites; nominate trainer for training and transferring courses to NRSD.
- NRSD will nominate technicians to participate the validating/comparison of forest maps (Using National land inventory map of 2020 for reference and field inspection);
- NRSD will nominate technicians to participate the training courses for receiving technology from France.

In the future

- NRSD proposes a cooperation with VietSCO on plastics pollution monitoring in the East Sea using remote sensing technology.
- NRSD proposes the French side to support NRSD with technology transfer, experts, satellite image

The following Implementation Plans were developed for NRSD collaboration in the project.

Capacity building		
When	Who	What
Before 18 sep 2021	Hoa Phan	Write to Tuan, Minh and Liem to ask the list of participants for the training, their background (level of expertise now), the software they use, the software languages they know
Before 25 sep 2021	GlobEO+CESBIO	Proposal of training content and agenda (for trainings in 2021) adapted to the trainees background
Before 8 oct 2021	GlobEO+CESBIO	Advanced training content and agenda (for trainings in 2021)
18-22 oct 2021	GlobEO+CESBIO	General training 1 (3h): Introduction to SAR - Theoretical
25-29 oct 2021	GlobEO+CESBIO	General training 2 (2x3h): SAR image properties and pre-processing – Theoretical and practical
8-12 nov 2021	GlobEO+CESBIO	Training on rice monitoring (3h) - Theoretical and practical
Feb-Apr 2022	GlobEO+CESBIO	Potential completion of the 2021 trainings
Feb-Apr 2022	GlobEO+CESBIO	Training for end users, depending on the WP7 outputs

Table 1. Implementation plan for capacity building and for validation/comparison

COMPARISON/VALIDATION		
When	Who	What
Before end of sep 2021	Stéphane Mermoz	To send the 2019 and 2020 rice maps for comparison/validation at least with inventory maps, first over the Mekong Delta and Red River Delta where the rice detection methods are calibrated.
From oct 2021	GlobEO+CESBIO	To interact with NRSD for results analysis
From oct 2021	GlobEO+CESBIO	Possibly, to list Vietnamese regions others than the Mekong Delta and Red River Delta, where the rice detection methods are simpler and not calibrated, for potential comparison/validation. If applicable, to send to NRSD the corresponding rice maps.

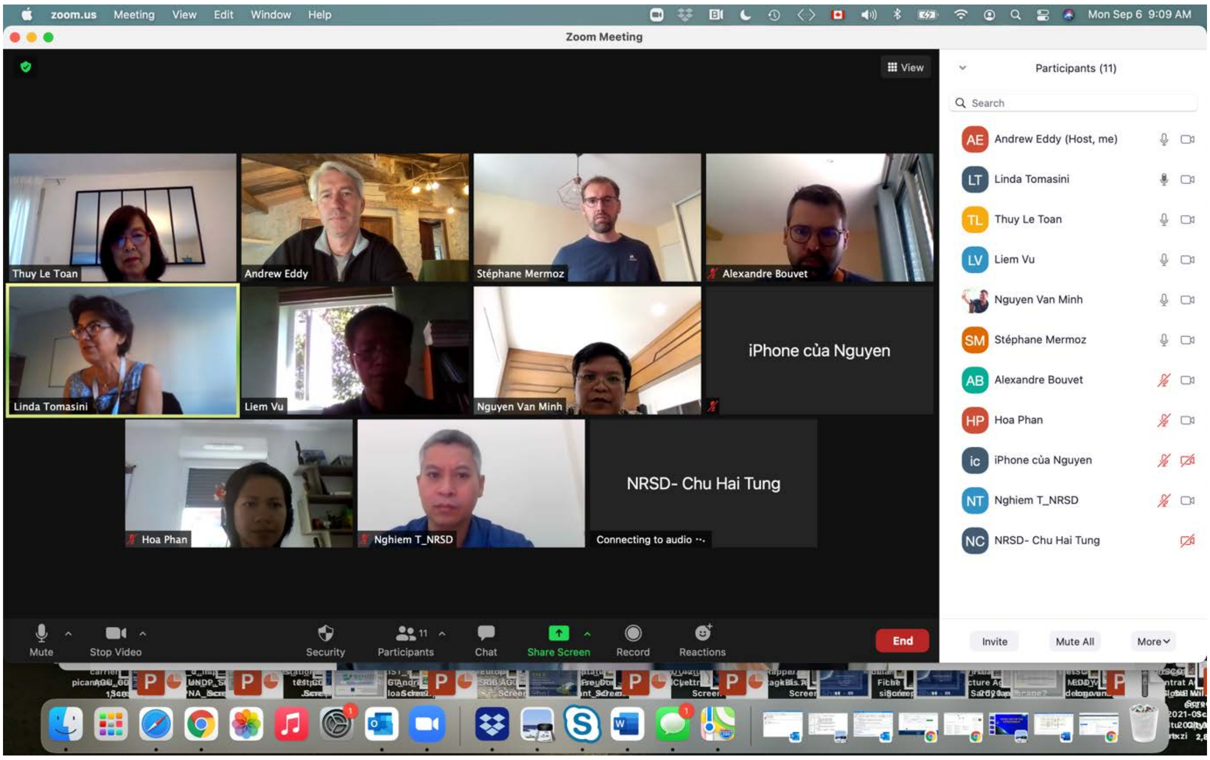


Figure 3. NRSD Bilateral discussion on Phase 1 objectives and roles

2.3 User Requirements

Summary statement of user requirements

	Category	Name	Description
1	VM-Rice	SR Map	Seasonal rice maps
2	VM-Rice	CD Map	Rice cropping density maps
3	V-ARRO	FE Map	Flood extent map – flood extent and % district affected
4	V-ARRO	FD Map	Flood duration map – extent of flood over time
5	V-ARRO	RAF Map	Rice crops affected by flood map – areas planted with rice affected
6	V-ARRO	SA Map	Saline intrusion and sea level rise impacts on rice per scenario

Table 2. The VietSCO operational products

Prospective users recognized that products exist at varying scales: national, provincial and local. Most users were interested in provincial scale products, but the project is expected to work at a variety of scales.

Users are interested in capacity building and training, and by a two thirds majority expect some or most of this to be in person rather than only online.

Users indicated they were willing to play an active role in the project, for example by:

- Exploiting, using and commenting.
- Evaluating fact and objectivity.
- Cooperation, research.
- Providing meteorological data.
- Using available data to warn diseases, rice yield.
- Contributing information about extreme weather conditions for agriculture.
- Providing basic theoretical and application of remote sensing to statisticians, persuading DARDs and units under MARD to apply maps.
- Receiving technology transfer and applying in practice.

The main outputs and benefits of the project are:

- Products of the project will be the basis for the study relevant implementing agencies.
- Products are used in natural disaster monitoring using remote sensing technology.
- Consultation for professional projects related to hydrometeorology and climate change.
- Creation of agricultural meteorological information news.
- Support for the direction and administration of natural disaster prevention.

The users expect that detailed products and data inputs for models, will be generated, with integration capabilities and high spatial and temporal resolution. Before publishing products, users felt it was important that these be validated with relevant research institutions that are part of the user community, such as: Institute of Meteorology, Hydrology and Climate Change (IMHEN), and others. Some of these stated objectives remain to be achieved and will be advanced through Phase 2 of the project.

2.4 User Conference in Hanoi – June 2022

Phase 1 of the VietSCO project ran from July 2020 through May 2022. The User Conference held in Hanoi on June 16 and June 17 reunited about fifty participants from a range of partners, users, and stakeholders, and aimed to present the results of this first phase to possible operational and academic users of VietSCO data and products.

Day 1 – 16 June 2022

Opening Session – Objectives and Success of Phase 1
(all sessions translated from English to Vietnamese)

08:30 Arrival, introductions – Vu Anh Tuan (VNSC)
09:00 Welcoming remarks – VAST
09:30 Overview of Viet-ARRO and VIMESCO Rice, the accomplishments of Phase 1 (Linda Tomasini, VietSCO co-lead)
10:00 Short demonstration of VietSCO Platform – Stéphane Mermoz (GlobEO)
10:20 Coffee break
10:45 Statements by Users
  10:45 MARD – CIS
  11:00 MONRE – NRSD
  11:15 MONRE – IMHEN

11:30 MARD – VNDMA
11:45 Donor community statement – UNDP interest in VietSCO
12:00 General discussion around VietSCO Platform and Phase 1 results
12:30 Lunch

Applied Session – Preparing for Operational Use of Satellites in Rice Monitoring and Recovery from Extreme Weather Events

14:00 VIMESCO Rice for Operational Rice Monitoring – Le Toan Thuy (CESBIO)
14:30 Generation of Monthly Rice Maps using satellite data – VNSC Ho Chi Minh City (Nguyen Lam Dao)
14:45 Viet-ARRO Applications for Risk Management – Stéphane Mermoz (GlobEO)
15:15 General Discussion on VietSCO Phase 1 results – Animation Vu Anh Tuan, Linda Tomasini
15:45 Coffee break
16:00 Possible content of VietSCO Phase 2 (planned new user communities, operationalization of VietSCO Phase 1 results) – Vu Anh Tuan (VNSC)
16:30 Discussion and Wrap-Up of Day 1 – Summary by Vu Anh Tuan (VNSC)
17:00 End of Day 1

Day 2 – 17 June 2022

Academic Session – Research results of Satellite Remote Sensing for Rice Monitoring and Risk Management

09:00 Impacts of climate change and human activities on rice agriculture in the Mekong delta– Le Toan Thuy (CESBIO)
9:20 Future climate scenarios for Vietnam – Ngo Duc Thanh (USTH)
9:40 Simulation of rice production in the Vietnam Mekong Delta under scenarios of climate change - Hoa Phan (CESBIO)
10:00 Machine Learning for Rice Monitoring using SAR data – Ngoc Tran (HUST)
10:20 Coffee break
10:50 Use of Remote Sensing for Flood Impact Assessments– Le Toan Thuy (CESBIO)
11:10 Calculating the socio-economic impact of typhoons using satellite data – Le Van Chon (VNU)
11:30 Open presentations and wrap up of academic session – Animation: Le Toan Thuy, Ngo Duc Thanh
12:00 Lunch

(Conclusions of the User Conference to be inserted in draft 2)

3. VietSCO products

The VietSCO products are based on Sentinel-1 time series. Rice monitoring methods were derived by CESBIO from past activities (e.g., from Phan, 2018), whereas the flood mapping method has been developed especially for VietSCO.

The rice maps, developed using the maximum increase indicator as described in Phan (2018), were validated during the GeoRice project, with more than 90% of accuracy. However, the postprocessing step for rice monitoring has been improved in the frame of the VietSCO project. To do so, we took the twelve rice seasons within a four-year period (2016-2020) and removed pixels with less than three seasons, which allowed to reduce noise and improve the delineation of the fields. We also applied a majority filter for cropping intensity mapping. Flood extend detection has been applied by using the multiscale framework for rapid change analysis using Sentinel-1 data from Lê et al. (2015). The method can be decomposed in two steps: deriving change detection matrices over patches for analyzing change dynamics, followed by a pixel wise analysis to derive the change maps. The multi-temporal analysis of flooded maps allowed to produce the flood duration maps. Permanent water bodies maps have also been derived to differentiate permanently flooded areas from flash floods. Then, flood maps estimated from Sentinel-1 images were generated by excluding permanent water bodies. Finally, the affected rice area has been assessed by the combined analysis of flood and rice maps. A pixel has been considered as affected if in both the rice and flood maps.

3.1. Description of VietSCO operational products

The **seasonal rice maps** (VM-Rice-SR map, Figure 4) are produced for one to four seasons per year depending on the geographic area, in the Mekong and Red River Deltas, from 2015 to 2020. The maps are compressed (deflate compression) and provided in GeoTiff (Raster) format. The selected projection is Geographic lat-long (datum WGS 84), data type is integer and pixel size is approximately 10x10m.

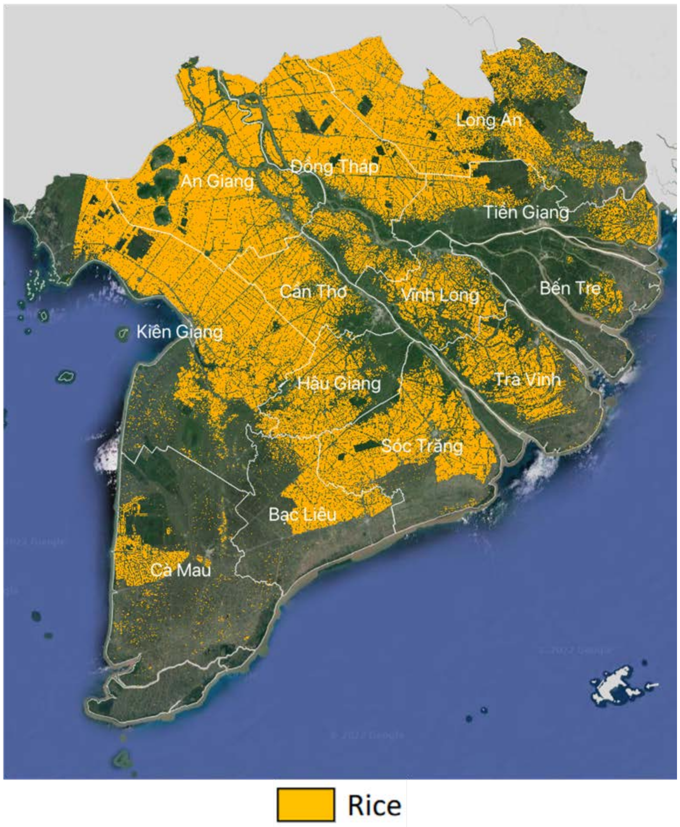


Figure 4: VM-Rice SR (Seasonal Rice) map. The map shows the spatial distribution of rice crops (in yellow) in the Mekong Delta. Dry rice season 2020

The **flood extent maps** (V-ARRO-FE map, Figure 5) are generated in the Mekong and Red River Deltas from 2016 to 2020, during the flood season (e.g., from August to December in the Mekong Delta). In the frame of the Viet-ARRO project, the flood maps are particularly scrutinized in Northern Vietnam in July 2018, just before and after the Son Tinh Typhoon (19-21 July 2018). Flood maps are generated every 6 days after the typhoon, until complete water recession. The maps are compressed and provided in GeoTiff format. The projection is Geographic lat-long (datum WGS 84), data type is integer and pixel size is approximately 10x10m, with smoothed pixels due to 30x30 pixels window analyses.

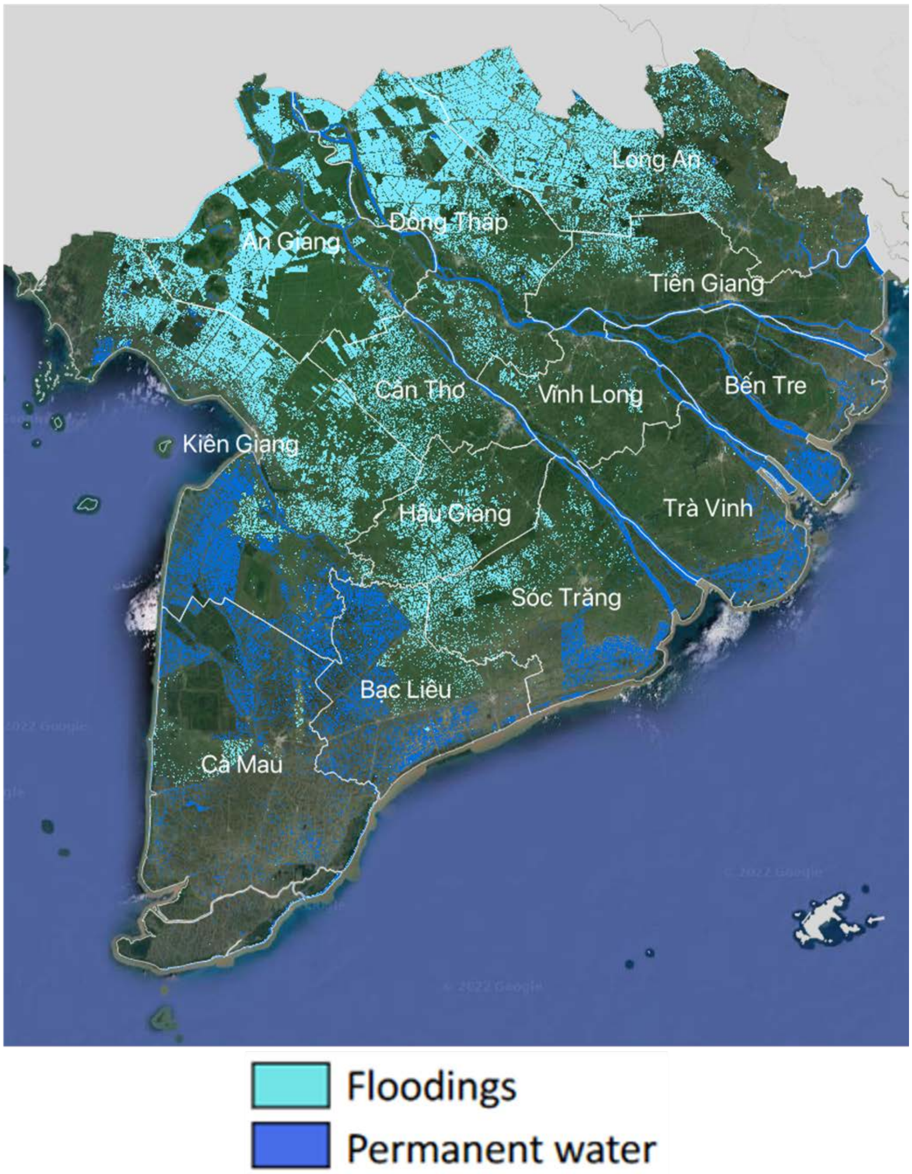


Figure 5. V-ARRO FE map. The map shows flooded areas in the Mekong Delta.

The **flood duration maps** (V-ARRO-FD map, Figure 6) are generated each week and are used to map flood duration. Flood duration is expressed in number of flooding days, from the beginning of floodings until recession. As for flood maps, flood duration maps are compressed and produced in GeoTiff (Raster) format. The projection is Geographic lat-long (datum WGS 84), data type is integer (provided duration is lower than 256 days) and pixel size is approximately 10x10m.

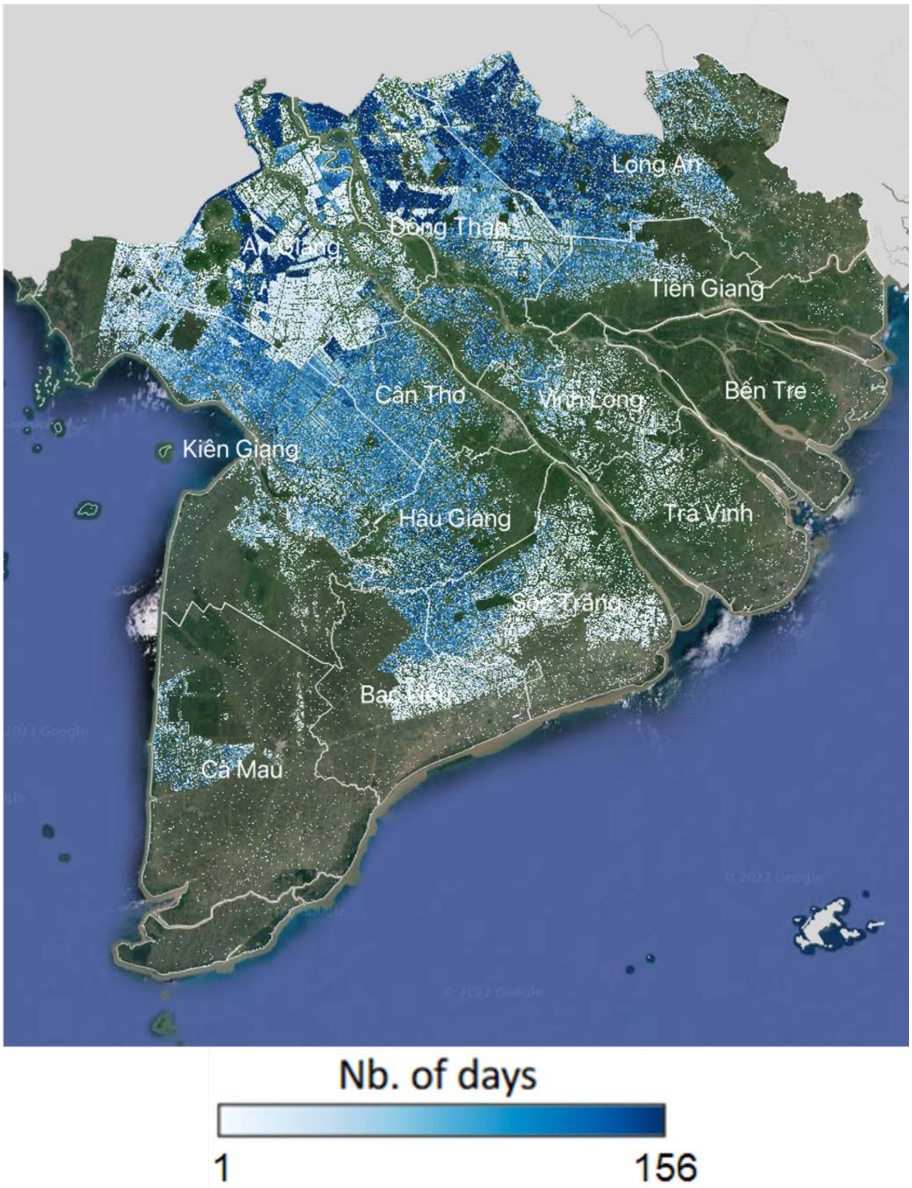


Figure 6. V-ARRO FD map. The multi-temporal analysis of flooded maps allows to produce the flood duration map above.

The **maps of rice crop affected by floods** (V-ARRO-RAF map, Figure 7) are obtained by comparing rice maps (VM-Rice-SR map) and flood maps (V-ARRO-FE map). These maps illustrate the detection of rice crops affected by floods and provide an estimate of the impacted rice crops surface area. The maps are generated for the Mekong and River Deltas from 2016 to 2021 and in Northern Vietnam during after the Son-Tinh typhoon. The maps are compressed and provided in GeoTiff (Raster) format. The selected projection is Geographic lat-long (datum WGS 84), data type is integer and pixel size is approximately 10x10m.

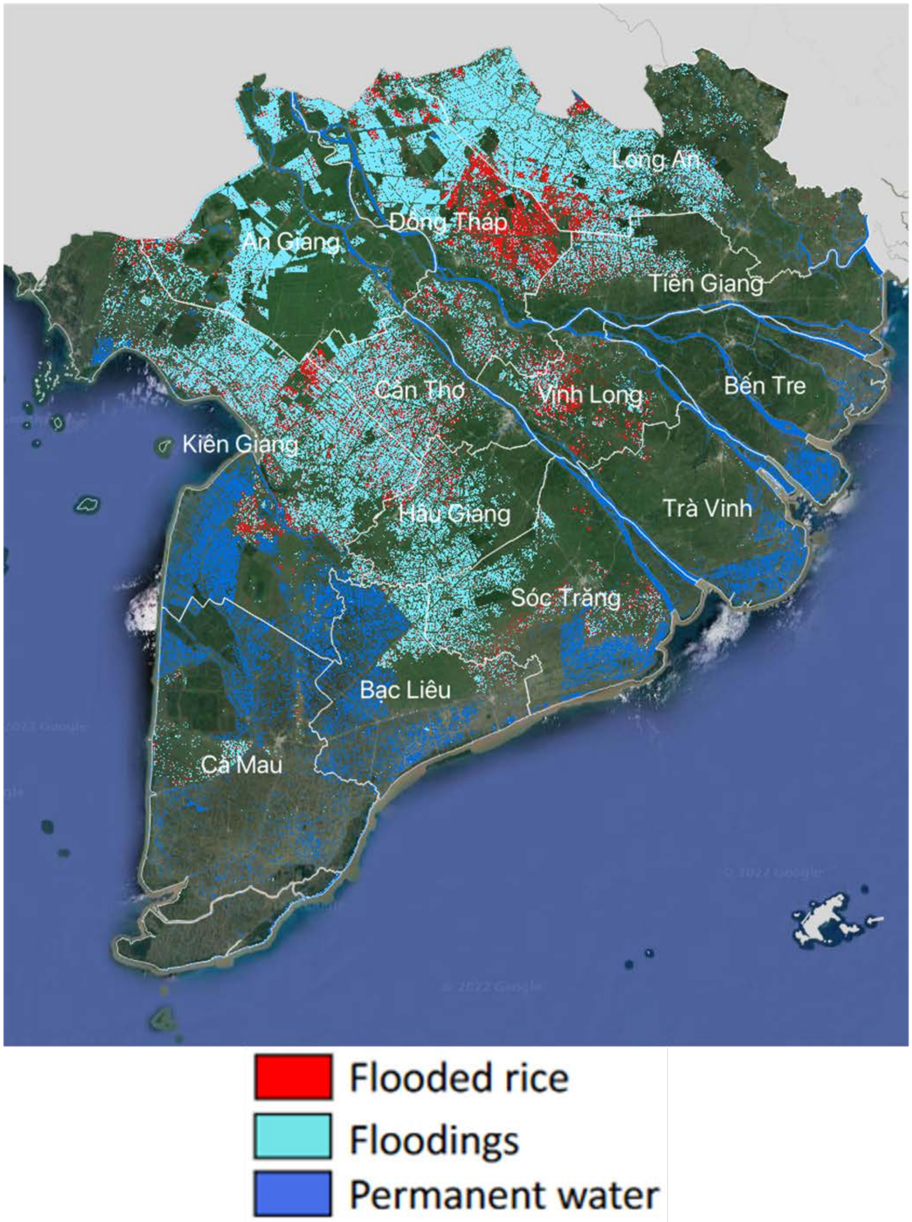


Figure 7. V-ARRO RAF map. Overlay of rice maps (VM-Rice SR map) and flood maps (V-ARRO FE map) leads to the detection of rice crops affected by floods.

3.2. Description of VietSCO pre-operational products

Crop calendar map (VM-Rice CC map), showing sowing dates estimated from the temporal behavior of the radar backscatter during the rice season**.** The map is in GeoTiff / Raster format (deflate compression). The maps are generated for each seasonal rice map. The selected projection is geographic lat-long (datum WGS 84). Data type is integer 16 bits with pixel values corresponding to the number of Julian days since the launch of Sentinel-1A (3 April 2014). Pixel size is approximately 10x10m.

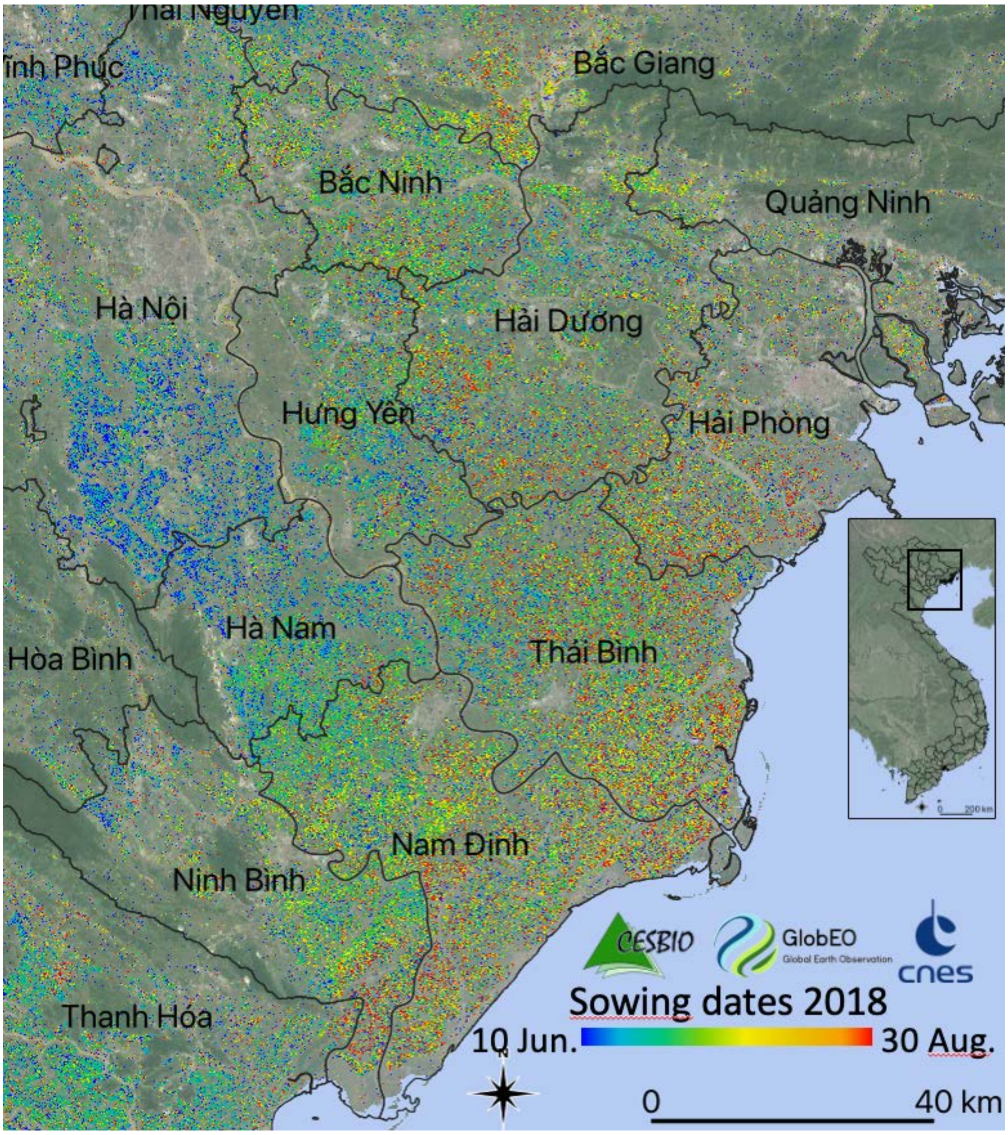


Figure 8. Rice sowing dates (VM-Rice CC Map) in Vietnam in the Red River Delta for the 2018 Summer-Autumn season. Sowing dates in the map range from 10 June 2018 to 30 August 2018. A large part of the rice crops in the region were sowed when the Son-Tinh typhoon occurred from 19 to 21 July 2018.

Rice crop phenological stage map (VM-Rice#6 RGS map) through the product Rice Growth Stage (Figure 9). The map in GeoTiff / Raster format (deflate compression) and is generated for each seasonal rice map. The selected projection is Geographic lat-long (datum WGS 84), data type is integer and pixel size is approximately 10x10m.

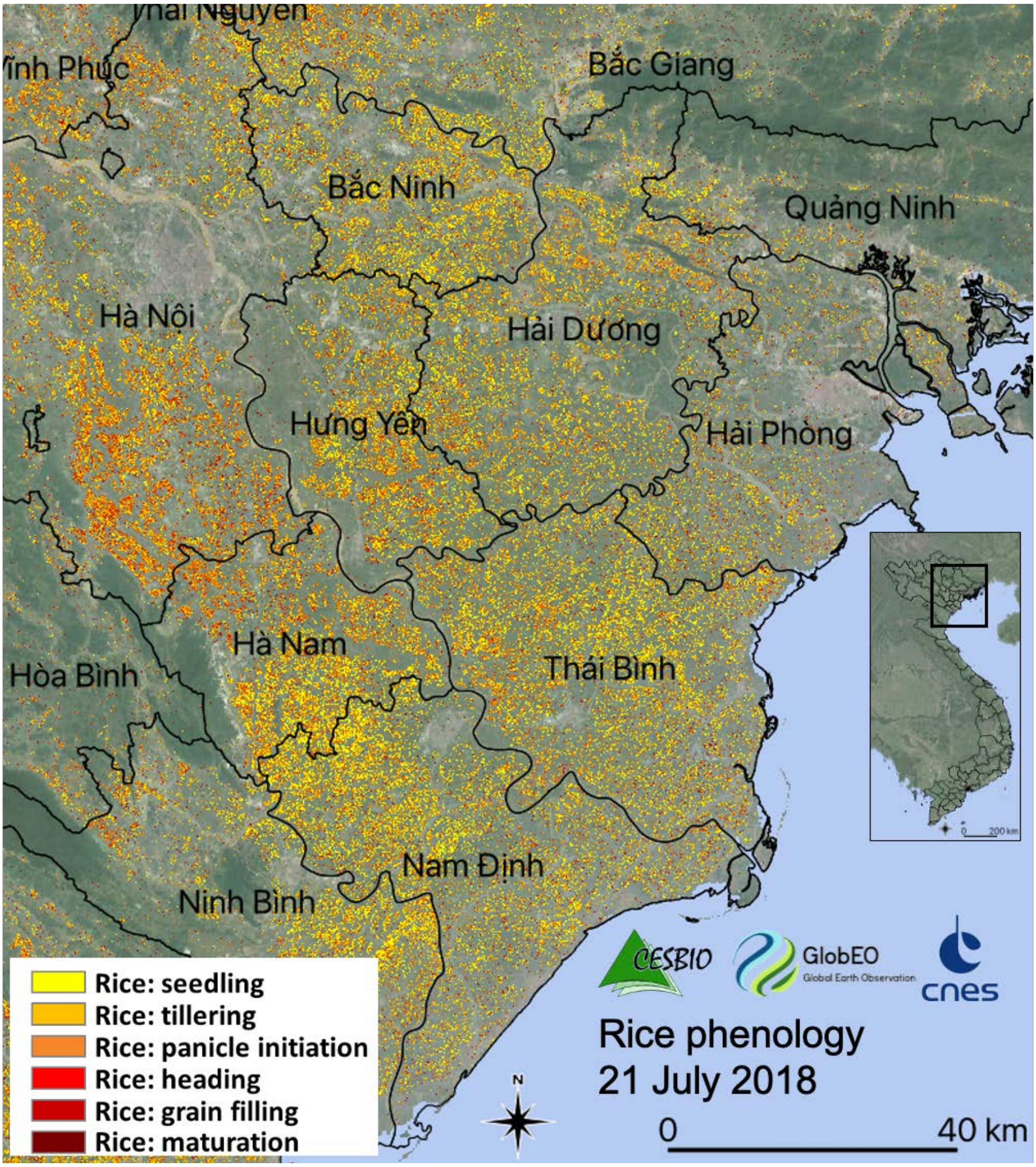


Figure 9. Rice Growth Stage map (VM-Rice RGS Map) in Vietnam in the Red River Delta on 21st July 2018. At that date, most rice fields were in the stage of seedling and tillering, and very probably destroyed by floods which last during many days. However, rice could be replanted after the floods for the Summer-Autumn season.

4. VietSCO Research Activities

Research activities addressed three topics, including the impacts of climatic and anthropogenic stressors on the rice production, the variations of flood dynamics and pattern effects on rice agriculture, and the monitoring of typhoons impacts on rice crops. The VietSCO products should allow the stakeholders in Vietnam to monitor the state of rice production, especially for the purpose of food security. For the longer term, the products can serve as a basis for climate adaptation and mitigation measures, and for actions concerning the Sustainable Development Goals of Vietnam.

In this context, the focus of the VietSCO science studies has been on the effects of climate change and human pressure on rice agriculture in the Mekong Delta. In Vietnam, the projected climatic impacts are expected to be very severe. Rainfall and temperature are expected to change the ecosystems in Vietnam,

Climatic projections show an increase in extreme weather (storms, drought, flood),
Sea level rise increases vulnerability to saline intrusion.

The effects of climate change have been exacerbated by human activities in the Mekong Delta:

- Subsidence of 2-4 cm/year, increasing risk of permanent inundation,
- Riverbed incision due to the decrease of sediment transport and sand mining,
- Changes in the Mekong River flow due to upstream hydroelectric dams,
- Intensive agriculture increases pollution and GHG emissions.

The main questions we addressed are 1) how climatic and anthropogenic stressors are affecting and will affect the rice production, and 2) what are the ways to adapt and mitigate the negative impacts? We thus addressed the rice production in the Mekong Delta to assess the changes in rice agriculture in the recent years and to understand the causes of these changes, and to attempt to projection in the future, under scenarios of climate change and human impacts. To do so, we used remote sensing for observations, and models and scenarios for projection. Note that the models and scenarios works have been conducted within the GEMMES-Vietnam project.

We evidenced for example severe drought in the dry season 2020, which led to harvest loss in coastal regions as shown in Figure 10.

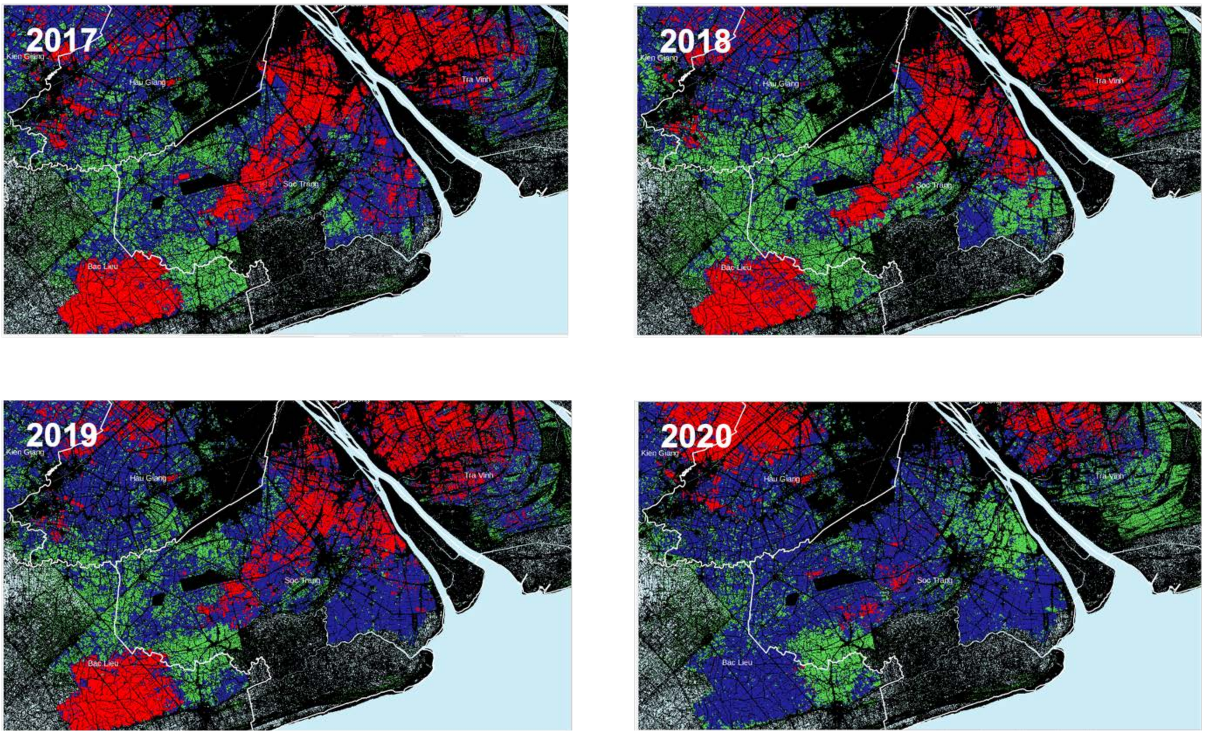


Figure 10. Annual changes in rice cropping density in the Coastal provinces of the Mekong Delta. In red: triple rice harvest, in blue: double rice harvest, in green: single rice harvest

We also assessed to what extent and where the land will become unsuitable to rice cultivation in future scenario of salinity intrusion. We thus quantified potential harvest loss due to salinity intrusion. We selected the VietSCO dry season rice maps and looked at where rice can grow. We found that 95.2% of rice harvest pixels found in region of salinity < 2 ‰. The potential impact of salinity intrusion on rice area under RCP 8.5 is summarized in Table 3. These results highlight the need of adaptation by farmers and regulation by authorities.

Table 3. Potential impact of salinity intrusion on rice area under RCP 8.5

Anthropogenic changes		Sensitivity Cases		Affected rice areas	
Subsi dence	**Riverbed level incision**	**Drought**	**Removing sluice gates**	**Thousand ha**	**%**
				33.74	2.18
X				45.39	2.94
X	X			208.07	**13.46**
X	X	X		202.78	**13.12**
X	X		X	336.33	**21.76**

By 2050, with RCP 8.5 (i.e., including sea level rise and River discharge), without riverbed incision, the salinity effect on rice area is marginal (3%). However, with riverbed incision of 15 cm/year due to sand mining, the percent of affected rice area could increase to 13%. The most potential impacted provinces are Tien Giang, Vinh Long, Tra Vinh and Soc Trang (see Figure 11).

The Mekong delta people already have adaptation measures for salinity intrusion (sluices, dykes, reducing the dry season rice). By 2050, with increased anthropogenic pressure, the impacts on rice area appear to be more severe. In particular, the freshwater provinces of Tien Giang and Vinh Long are projected to be unsuitable for rice cultivation.

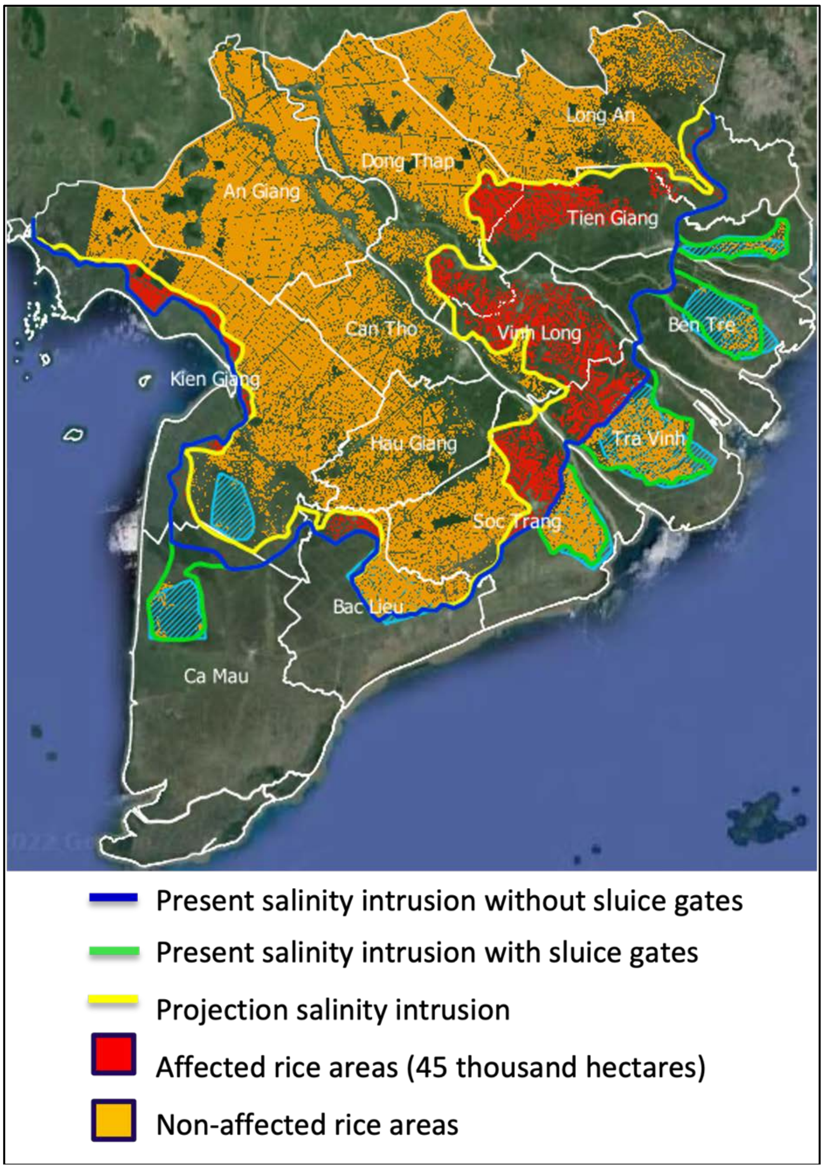


Figure 11. Impacts on rice area significantly increase with riverbed incision caused by river sand extraction. Simulation from Eslami et al., 2021 under RCP 8.5 (Discharge and Sea level rise), Extreme subsidence Riverbed level incision (15cm/year) in 2050.

With scenarios of sea level rise and ground water extraction, a large part of the delta is projected to be below sea level. The percent of affected rice area could increase to 30%, in the scenario of (moderate) increase of ground water extraction.

The main mitigation measures to reduce human pressure on the environment are nature-based solutions of adapted number of crops per year, limitation of ground water over-exploitation and of riverbed incision by reducing sand extraction.
The short-term adaptation measures include building protection infrastructure in areas projected to be impacted and reservoirs to retain irrigation water, avoiding planting in areas likely to be harmed by seawater intrusion for winter-spring rice, changing crop calendar, exploring more efficient alternatives to irrigation and combined aquaculture and rice growing operations, and changing crop types or change to other land use type.

Flood detection using Sentinel-1 has also been applied to detect the effects of flood on the rice agriculture, for 1) assessing the effect of changing flood dynamics and patterns on rice in the Mekong Delta (following a VNDMA requirement), and 2) assessing the effect of the unexpected flood event consecutive to typhoons. We were able to plot the inter-annual variations of flood extent in the Mekong Delta, and to estimate accurately the peak periods of flood season as shown in Figure 12. Because of annual changes in flood temporal and spatial distribution, farmers had to adjust and change rice crop calendar.

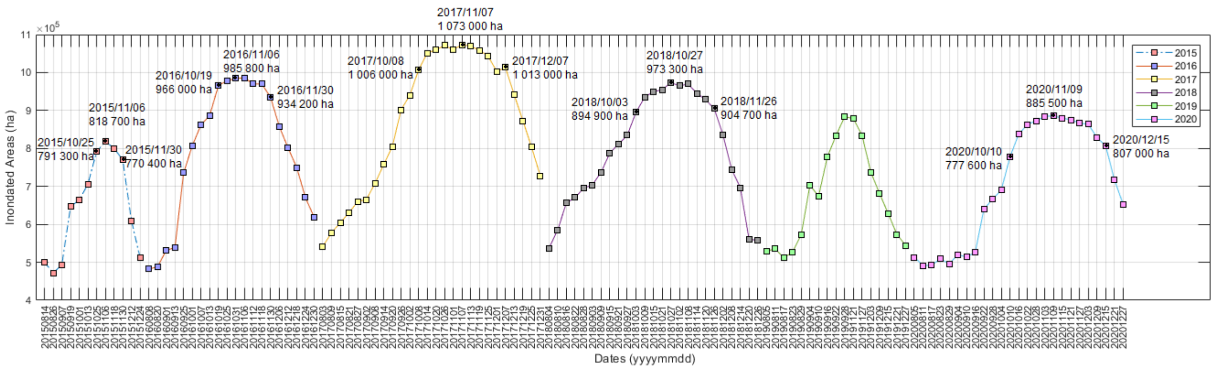


Figure 12. Inter-annual variations of flood extent in the Mekong Delta, obtained from flood mapping using Sentinel-1 data.

Flood and rice mapping has also been used for assessing typhoons impacts on rice crops. During the peak typhoon season (August to October), central Vietnam is greatly affected as the typhoon enormous strength can make big damages. And from June to August, tropical cyclones can provoke several heavy rains or rainstorms in the North of Vietnam. In regions usually affected by typhoons in Vietnam, i.e., in Central provinces, the rice calendar has been adapted to the timing of typhoons. That's why Damrey (November 2017) and Molave (October 2020) typhoons provoked severe floods in Central provinces, but outside the rice season. In 2020, despite the numerous typhoons that occurred in Central Vietnam (such as Nangka, Saudel, Molave, Goni, Etau, Vamco, etc.), surface areas and production of rice have been constant between 2016 and 2019 in the Centre of Vietnam according to the General Statistics Office of Vietnam (GSO), and the rice calendar has not changed much the last years according to our SPOT VGT-based analysis.
We thus investigated the tropical cyclones that occurred in Vietnam from 2015-2020, which could indirectly impact rice cultivation in North Vietnam. Son-Tinh typhoon happened on 19-21 July 2018 in the Red River Delta. It was a deadly storm that devastated the Red River Delta and caused severe flooding and landslide. Inundated rice areas were approximately 40 000

hectares[1]. Rice was at the start of the summer-autumn crop season, and large areas of growing rice were inundated, as shown in Figure 13.

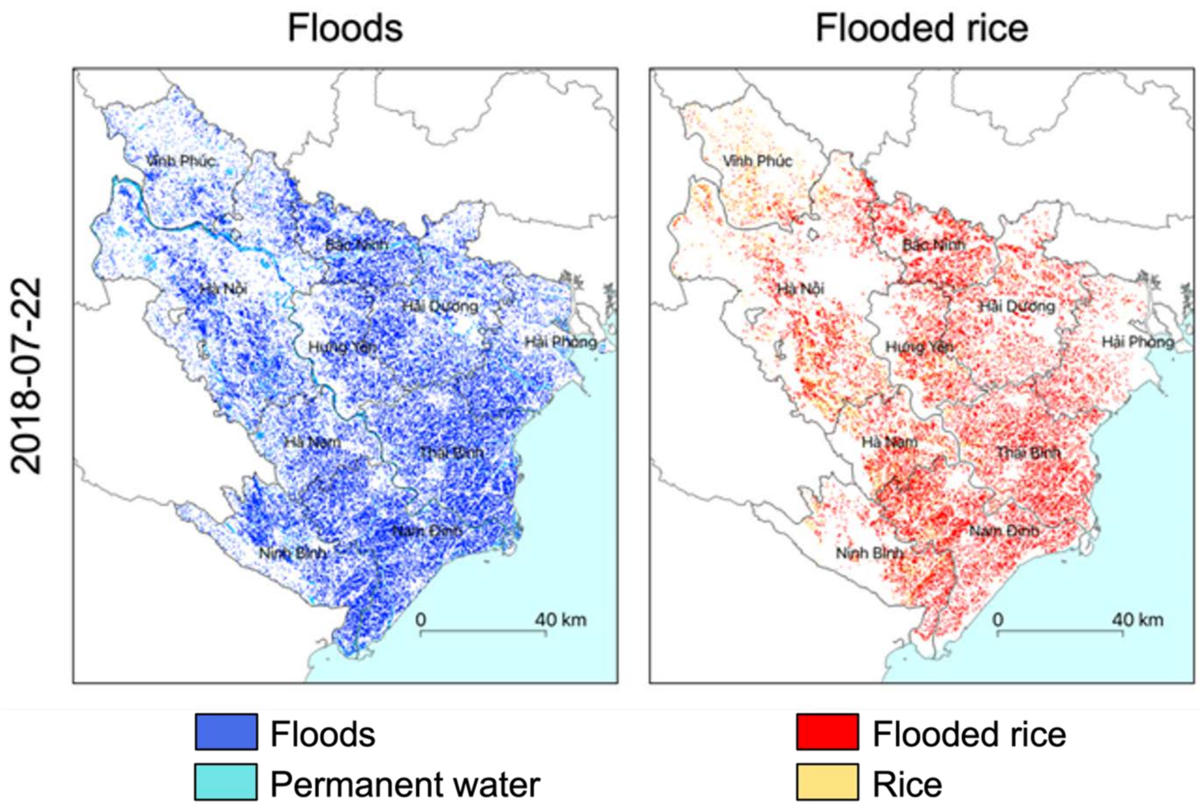


Figure 13. Flood maps just after the Son-Tinh typhoon (left) and unflooded and flooded rice (right)

We assessed for each province the total rice area and for each Sentinel-1 image after the typhoon, the flooded area and the flooded rice, as shown in Table 4. The recession of flood is visible on the 3 august S1 image. It was thus possible for the farmers to replant rice with a delay, which was confirmed using our analysis based on SPOT data.

[1] https://en.vietnamplus.vn/downpours-flooding-wreak-havoc-in-northern-localities/135075.vnp

Table 4. Estimation of the impacted rice crops surface area.

Province	Rice area (ha)	Flooded area 20180722 (ha)	Flooded rice 20180722 (ha)	Flooded area 20180803 (ha)	Flooded rice 20180803 (ha)	Flooded area 20180815 (ha)	Flooded rice 20180815 (ha)
Thai Binh	50981	67335	41658	6342	3880	1145	254
Vinh Phuc	15742	15315	3946	2725	23	2395	27
Bac Ninh	25194	29848	20071	3555	2097	650	67
Ha noi	55818	66200	30135	10624	927	6572	173
Nam Dinh	51913	69614	41856	13552	7654	3936	1512
Ninh Binh	24081	40457	16439	13822	4391	5680	892
Hai Phong	14480	31147	11585	5894	2149	1787	224
Hung Yen	22103	23075	15044	736	131	448	14
Hai Duong	32940	45539	24443	2754	842	1266	90
Ha Nam	24913	22774	14237	1658	330	738	7

Science and research activities also included extensive work on socio-economic linkages. The Project aimed to determine whether EO could be used to examine impacts of typhoons, correlated with household surveys.

5. VietSCO socioeconomic studies

5.1. Satellite data in economic analysis

A common question: quantify causal effect of one set of variables on another variable. E.g., yield responses to fertilization. The ideal case is to use experimental data in which land lots are randomly divided into groups with different amounts of fertilizers, and crop yields on these land lots are measured. Such experiments are typically performed in very small scales.
Most economic data are observational, from on-the-ground household surveys and/or censuses. Household surveys provide detailed data at household level but collect a very small sample. Censuses give statistics at district, or country levels, but do not show heterogeneous farming practices among households.
Remote sensing can create data at much finer spatial resolution (e.g., Jain et al. (2016) used SkySat data to map wheat yields in land lots with areas < 0.3 ha in Bihar, India), and at regional to global scales and over multiple time periods.
Cheap and high frequency observations follow changes in cultivation and management strategies, especially important under climate change.
It is still difficult to infer causality from observational data, e.g., a farmer's number of fertilizers is detemined partially by his choices, which are affected by his own knowledge, experiences in adapting to changing environmental conditions. Fertilization is not exogenous.
Assume each land lot has 2 potential outcomes:

- $y_i(0)$ is the crop yield given no fertilization (control), and
- $y_i(1)$ is the crop yield given fertilization (treatment).

We cannot observe both $y_i(0)$ and $y_i(1)$ for a given land lot i, but rather only the realized value :

$$y_i = \begin{cases} y_i(0) & \text{if } D_i = 0 \\ y_i(1) & \text{if } D_i = 1, \end{cases}$$

where D = 1 if the land lot is exposed to treatment and 0 otherwise. Cannot observe causal effect of fertilization.
After conditioning on appropriate regressors, if

$$E(\varepsilon_i | D_i) = 0, \qquad (*)$$

then regression analysis can estimate treatment effect.

The simplest case: $y_i = \beta_0 + \delta D_i + \varepsilon_i$.

Least squares regression $\hat{\beta}_0 = (\bar{y}|D_i = 0)$, control group

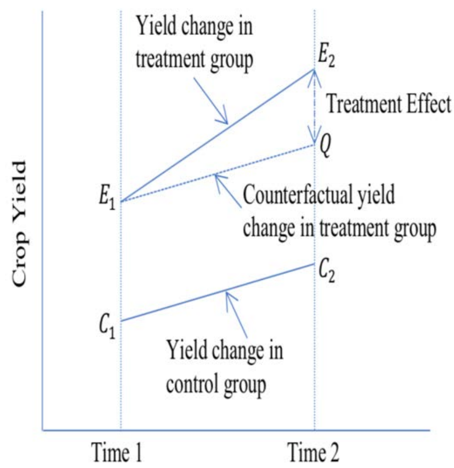
$\hat{\beta}_0 + \hat{\delta} = (\bar{y}|D_i = 1)$, treatment group.

An estimate of treatment effect: $\hat{\delta} = (\bar{y}|D_i = 1) - (\bar{y}|D_i = 0)$.

Sometimes it is very difficult to satisfy assumption (*) due to our incomprehension, data unavailability, simultaneity, dynamic effects, measurement error, nonrandom sampling. → Cannot have a consistent estimate.
Method of instrumental variables (IV) was proposed to get round this endogeneity problem and environmental indicators from satellite data have been potential candidates for instruments.
It is implicitly assumed during treatment period, other factors of treatment and control groups do not change.
Given that things always evolve over time, we should measure crop yields of both groups at least one time period before treatment and at least one time period after treatment.

Difference-in-differences (DID) method

Crop yields in treatment and control groups are represented by lines E and C.
At time 1, both groups do not receive fertilization and their yields are points E_1 and C_1.
Then, fertilizers are spread on treated land lots and both groups are measured again at time 2.
$E_2 - E_1$ cannot be interpreted as effect of fertilization.
DID assumes that in the absence of fertilization, group-specific trends in crop yield would be identical.
Counterfactual crop gain in treated land lots is illustrated by dotted line E_1Q.
Treatment effect $(E_2 - E_1) - (C_2 - C_1)$.



DID is often combined with matching to enhance likelihood of parallel trend assumption being valid—matching treatment units with control units that are characteristically equivalent.
Rich data from satellites allow researchers to use multivariate matching and secure a robust DID estimate.
Extensive satellite data in the form of numerous variables call for variable selection, e.g., Engstrom et al.'s (2017) study of poverty from space: there are in total 28 spatial features.
Least absolute shrinkage and selection operator, or **lasso**, introduced by Tibshirani (1996), adds a constraint to a regression model to enforce parsimony.

Given a linear regression model $y_i = \beta_0 + \sum_{j=1}^{p} x_{ij}\beta_j + \varepsilon_i, \qquad i = 1, \dots, n,$

lasso forces the sum of the absolute values of the regression coefficients to be less than a fixed value t.

$$\widehat{\boldsymbol{\beta}}_{\text{lasso}} = \underset{\boldsymbol{\beta}}{\operatorname{argmin}} \left\{ \sum_{i=1}^{n} \left(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j \right)^2 + \lambda \sum_{j=1}^{p} |\beta_j| \right\},$$

where λ is the penalty parameter. As λ increases, $\widehat{\boldsymbol{\beta}}_{\text{lasso}}$ converges to the zero vector.
Lasso eliminates parameters in the model, enlarging bias at the benefit of smaller variance. We pick strongly significant spatial features which are instructive welfare indicators for monitoring and targeting poverty. Jain (2020) stated that much of measurement error in satellite data products is not random. First source of error is from sensor attributes, the angle of the satellite with respect to the earth's and the sun's surfaces, and atmospheric circumstances.
Since these data are likely to be inconsistent across space and time, radiometric calibrations and atmospheric corrections are required to convert radiance data to surface reflectance data.
Second popular source of error is induced by cloud cover and haze. It is important to have satellite imagery preprocessed and corrected. In addition, it is essential to assess satellite image accuracy using independent validation data. E.g., dragon fruit farmers in Vietnam usually use lamps at night in artifically induced flowering process. Nighttime luminosity in these regions is boosted, which does not mean that there is more economic activity.

5.2. Satellite data in agriculture production

Typical applications of satellite data in agriculture

- Quantifying yield variations
- Crop monitoring and yield forecasting
- Mapping land uses and land cover

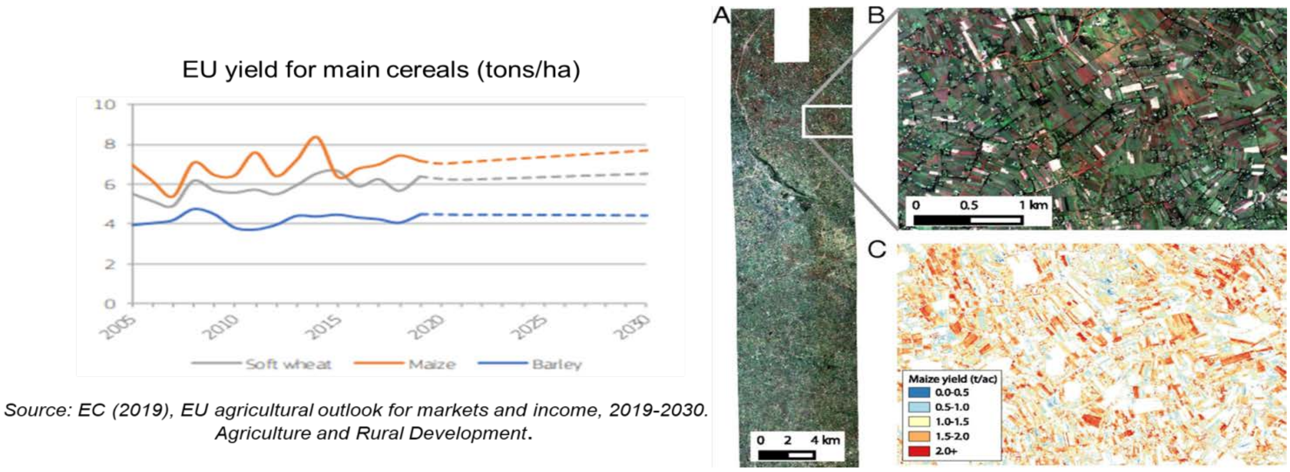
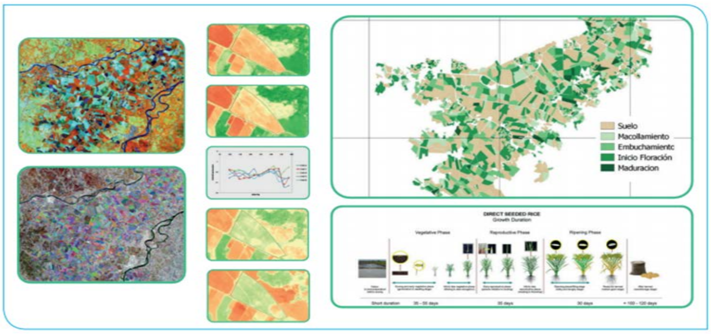


Figure 14. Satellite data in crop monitoring and yield forecasting

- Crop development monitoring and crop production estimate is very important for all countries
- Satellite data have been widely used for monitoring crop condition and productivity



- Land-use and land-cover change is one of the most important components of global environmental change
- Satellite remote sensing is an ideal technology for large-area land cover classifications

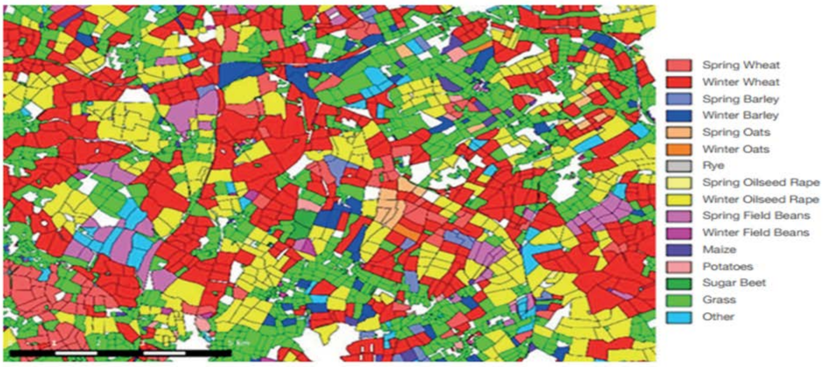


Figure 15. Satellite data in land uses and land cover

5.3. Satellite data in agriculture insurance

- Crop insurance can offer part of the solution to growers by compensating crop yield losses.
- But most farmers have not purchased crop insurance (where available) though facing many challenges including impacts of climate extremes (e.g., droughts, floods).
- Several barriers:
  - a detrimental cycle of adverse selection
  - poor results
  - increasing premium costs

Goslinga R. (2018)

Types of Agricultural Insurance

Indemnity-based Insurance:

- Payouts/claims based on an actual loss incurred by an insured party
- High cost
- Unavailable in rural areas
- Moral hazard: is the tendency for clients to be more careless of protecting their insured assets against losses since they are paid when losses occur

- Adverse selection: often refers to a situation in which insurers have information that clients do not have or vice versa
- Unaffordable for most smallholder owners

Index insurance:

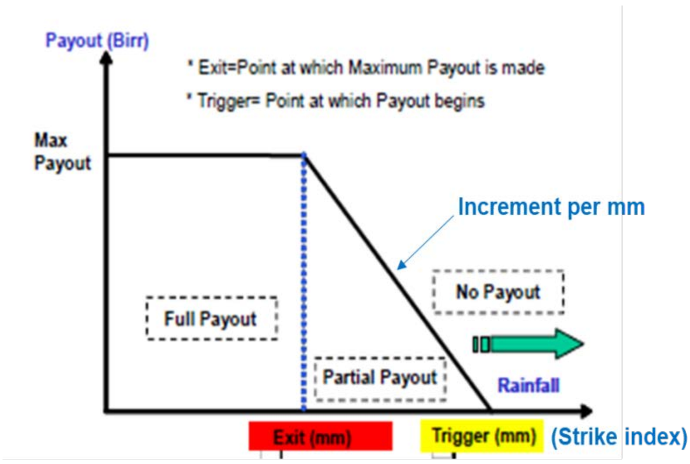
- Does not suffer from the problems of traditional insurance
- Payouts based on the external indicators/indices that trigger a payment to all policy holders within a geographically defined area
- Affordable for smallholder farmers in developing markets
- Types of index insurance:
    - Area-yield index insurance
    - Weather index insurance
    - Vegetation index insurance

Area-yield index insurance

- Claims based on the realized average yield of an area such as a county or district (typically 50–90 percent of the area average yield)
- Claims are paid if the realized average yield for the area is less than the insured yield, regardless of the actual yield on a policyholder's farm
- Realized average yield are calculated by loss assessors using crop cutting experiments in randomly selected farms
- Requires historical area yield data on which the normal average yield and insured yield can be established, which can often be difficult to obtain

Weather/vegetation index insurance

- Claims based on realizations of a specific index measured over a pre-specified period
- The insurance can be designed to protect against index deviations that are expected to cause crop losses
- An indemnity is paid whenever the realized value of the index exceeds or falls short of a pre-specified threshold
- Common weather indices: meteorological (rainfall, temperature), drought (SPI) and flood, climate (ENSO)
- Common vegetation indices: NDVI
- The indemnity is calculated based on a pre-agreed sum insured per unit of the index (for example, dollars/millimeter of rainfall)
    - The index cannot be manipulated by either the insured or insurer
    - Requires to monitor the index only, allowing to operate at a low cost



- Barriers:
    - Basis risk: the mismatch between the payout and actual losses leading to a probability that the growers may not be reimbursed even when losses occur

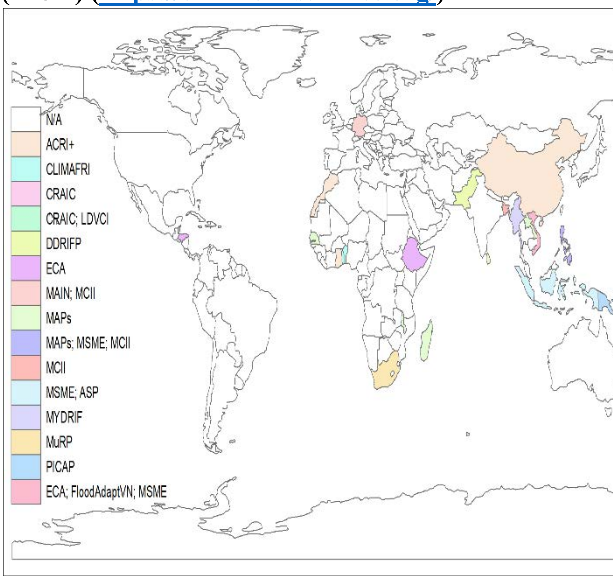
- Can occur in three forms: design, temporal, and geographical (or spatial) basis risk
- Ground-based index insurance products:
  - ✓ Rely on historical data for design, pricing, and calibration of products.
  - ✓ Data must meet commercial insurer and reinsurer requirements such as long historical data with only a small percentage of missing or out-of-range values of the total dataset, the distance between weather stations and insured farms, secure and trustworthy data recording
  - ✓ Difficult to operate in rural areas where the weather stations are often very scattered
  - ✓

Characteristics of Different Types of Agricultural insurance
GSM Association (2020):

	Set-up costs	Operational costs	Claim settlement speed	Risk of moral hazard and adverse selection	Basis risk	Actuarial difficulty
Indemnity-based	Medium	High	Slow	High	Low	Low
Area-yield index	Low	Medium	Slow	Low	Low	Low
Weather index	High	Low	Fast	Low	High	High

Global Implementation

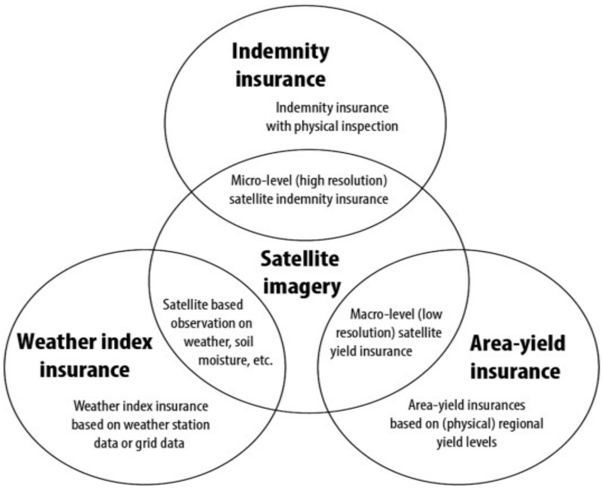
Map of insurance projects implemented globally using data from Munich Climate Insurance Initiative (MCII) (https://climate-insurance.org/)



Climate Risk Adaptation and Insurance in the Caribbean (CRAIC)	Jamaica, Saint Lucia, Gren Belize, Trinidad & Tobago
Economics of Climate Adaptation Studies (ECA)	Ethiopia, Honduras, Vietnam
Loss and Damage in Vulnerable Country Initiative (LDVCI)	Jamaica, Saint Lucia, Grena
Multi-Actor Partnership on Climate and Disaster Risk Financing and Preparedness in the Context of the InsuResilience Global Partnership (MAPs)	Laos, Sri Lanka, Malawi, Madagascar, Senegal, Philip Antigua and Barbuda, Barba Grenada
Advancing Climate Risk Insurance Plus (ACRI+)	Barbados, China, Ghana, Mo
MAIN Germany: Economy of Climate Change - new MAnagement INstruments to mitigate the risks of climate change in state and economy	Germany
MCII Contribution to the InsuResilience Global Partnership and V20	Germany, V20 Countries (Bangladesh, Phillipines)
CLIMAFRI: Implementing Climate-sensitive Adaptation Strategies to Reduce Flood Risk in the Transboundary Lower Mono River Catchment in Togo & Benin	Togo & Benin
Investigating the Feasibility of Municipal Risk Pooling as an Adaptation Finance Measure (MuRP)	South Africa
Designing a Disaster Risk Insurance Framework for Pakistan (DDRIFP)	Pakistan
Myanmar Disaster Risk Financing (MYDRIF)	Myanmar
Integrating Ecosystem-Based Approaches into Flood Risk Management for Adaptive and Sustainable Urban Development in Central Viet Nam (FloodAdaptVN)	Viet Nam
Promoting Climate Risk Insurance for the Micro, Small and Medium enterprise (MSME) Sectors of Indonesia, Philippines and Viet Nam	Indonesia, Philippines, Viet N
Adaptive Social Protection (ASP)	Indonesia
Pacific Insurance and Climate Adaptation Programme (PICAP)	Fiji, Papua New Guinea, Sol Islands and Vanuatu

Figure 16. Weather/vegetation index insurance using satellite data

- Basis risk: cannot be eradicated completely but can be reduced
- Satellite data: are spatially continuous across large areas of the earth, available in near real-time, can be freely accessible and available, have extended historical records, are difficult to influence by either the insured or insurer



5.4. Impact of climate change on rice production in Mekong Delta

Data

For rice production, data come from two main sources:

- Satellite data for information about rice cultivated area
- Survey data from VHLSS to calculate the average yield per hectare in each rice crop.

Then we calculate the yield of each crop by multiplying the average rice yield per hectare by the rice area from satellite data. For climate indicators, daily temperature and daily precipitation are from WP1.

Methodology

Generalized additive model (GAM):

Models were fit using a generalized additive model (GAM) which is a generalized linear model with a linear predictor involving a sum of smooth functions of covariates (Wood, 2006). The response variable (rice yield) *yield* was modelled as a non-linear (f) function of predictor variables (x) for each district (i) and year (j):

$$
\begin{aligned}
&yield_{ij} = \alpha + f(x_{ij}) + z_i\varphi + \varepsilon_{ij} \\
&yield_{ij} \sim \mathrm{N}(\mu_i, \sigma) \qquad (1) \\
&\varepsilon_{ij} \sim \mathrm{N}(0, \sigma^2)
\end{aligned}
$$

A random effect (φ) for each district (Z_i) was included to account for the repeat measurements for each year at the district level. A thin plate regression spline was selected for the non-linear function (or smoother). The model structured was kept simple, i.e., with a single predictor variable such as rainfall or temperature, so that it was transparent and suitable for investigating and developing a weather index insurance purpose. Complex models including many predictors and intricate model structures may be more appropriate for long term yield forecasts, but not necessarily for the development of weather index insurance, which needs to be simple and transparent so that it can be communicated to a range of stakeholders.

The threshold value (and its associated uncertainty) for those weather variables showing a (non-) linear change (i.e., a threshold response) that resulted in an increase in the rate of yield decline was quantified using threshold regression analysis (Fong, Huang, Gilbert, & Permar, 2017). A two-phase segmented threshold model is:

$$\eta = \alpha_1 + \alpha_2^T z + \beta_1 (x - e)_+ + \gamma x \quad (2)$$

where e denotes the threshold parameter, x is the predictor variable with threshold effect, z is additional predictor variables, excluding the threshold variable of interest (x). The hinge function is $(x-e)_+$, which equals $x-e$ when $x > e$, and 0 otherwise. Uncertainty in threshold estimates was computed using bootstrapping (n=1000), which was used to generate 95% confidence intervals.

Flexible temperature-binning analyses:

To measure the economic effect of climate change which measured by the variation of rainfall and temperature on rice production in the Mekong Delta, we applies the estimating equation:

$$area_{it} = \beta_{0+}\beta_1 temp_{it} + \beta_3\, precip_{it} + \alpha_i + \varepsilon_{it} \quad (3)$$

and

$$yield_{it} = \beta_{0+}\beta_1 temp_{it} + \beta_2 temp^2_{it} + \beta_3\, precip_{it} + \beta_4\, precip^2_{it} + \alpha_i + \varepsilon_{it} \quad (4)$$

where: $area_{it}$ is the rice-cultivated area of district i in year t; $yield_{it}$ is the yield per hectare of district i in year t; $temp_{it}$ and $precip_{it}$ are the average temperature and precipitation over a crop's growing season in district i in year t, and α_i is time-invariant district fixed effects.

In addition, to capture non-linear impact of weather on rice production, we construct temperature bins to account for extremely cold/hot days. Krishnan, et al. (2011) emphasizes that rice is originated in tropical or subtropical areas which is sensitive to the critically low and high temperatures normally below 20˚C and above 30˚C. In addition, Le Houérou et al. (1993) and Rötter et al. (1999) also reveal that the optimal temperature thresholds of rice is 25-30°C while the lower range and upper range are 7-12°C and 35-38°C, respectively . Based these studies and the distribution of temperature in the data set, we then classified temperature into bins of 2°C and then average temperature is divided into 10 bins (below 20°C, 20°C–22°C, 22°C–24°C, 24°C–26°C, 26°C–28°C, 28°C–30°C, 32°C–34°C, 34°C–36°C above 36°C).

For each crop season, we count the number of days that have average temperature in each bin and denote it as T_{pit}, p= 1, . . . , 9. In this research, we need to drop one bin to avoid the perfect collinearity and the 26-28°C bin was chosen as the omitted (reference) bin because this temperature range is beneficial for rice crops.

Therefore, to estimate how harmful higher temperatures are for crop, we use a flexible temperature binning approach with the estimating equation as follow:

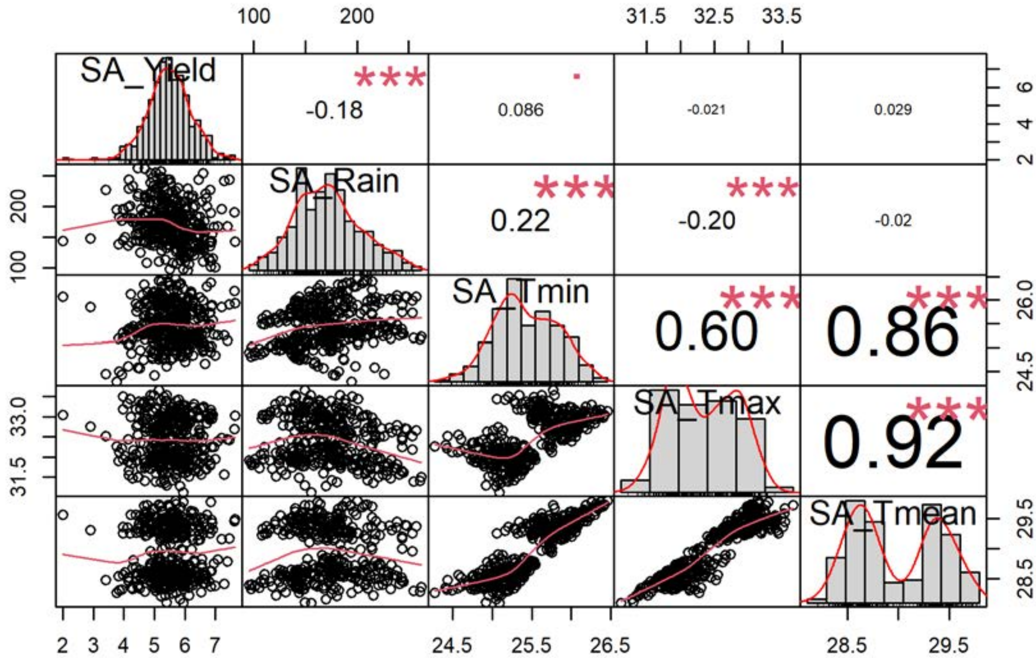
$$y_{it} = \beta_0 + \sum_{p=1}^{9} \beta_p T_{bit} + \alpha_i + \varepsilon_{it} \quad (5)$$

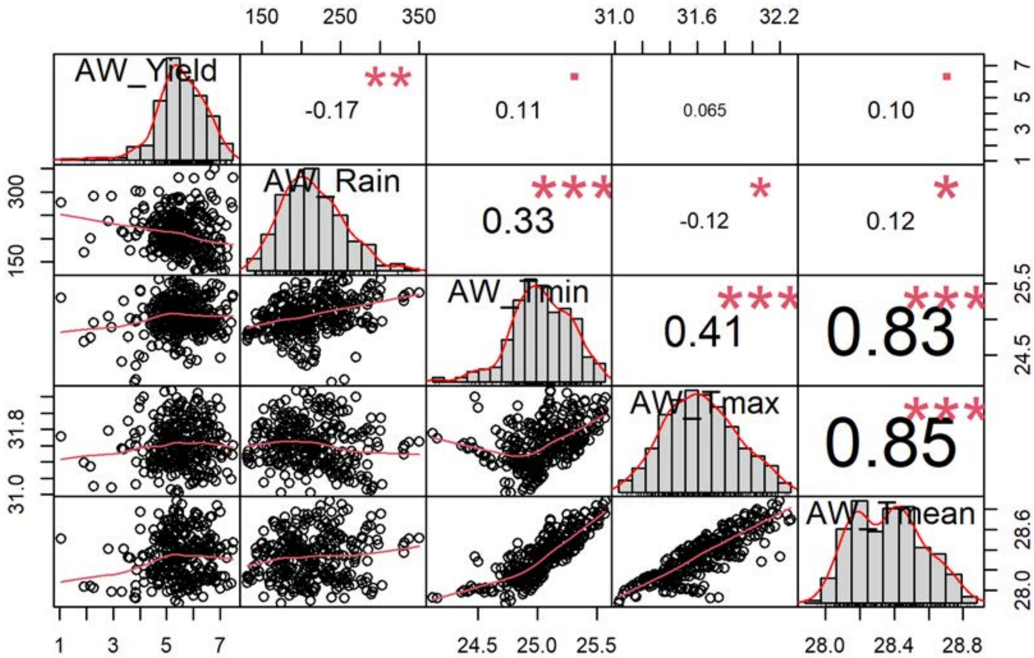
where:

- y_{it} is the yield per hectare of district i in year t
- T_{bit} represents the number of days in the growing season that fell into specific temperature and precipitation ranges (in the b^{th} bin), respectively in year t at district i
- α_i is time-invariant district fixed effects, and ε_{it} is a stochastic error term.

5.5. Primary Results

Generalized additive model (GAM) and threshold analyses





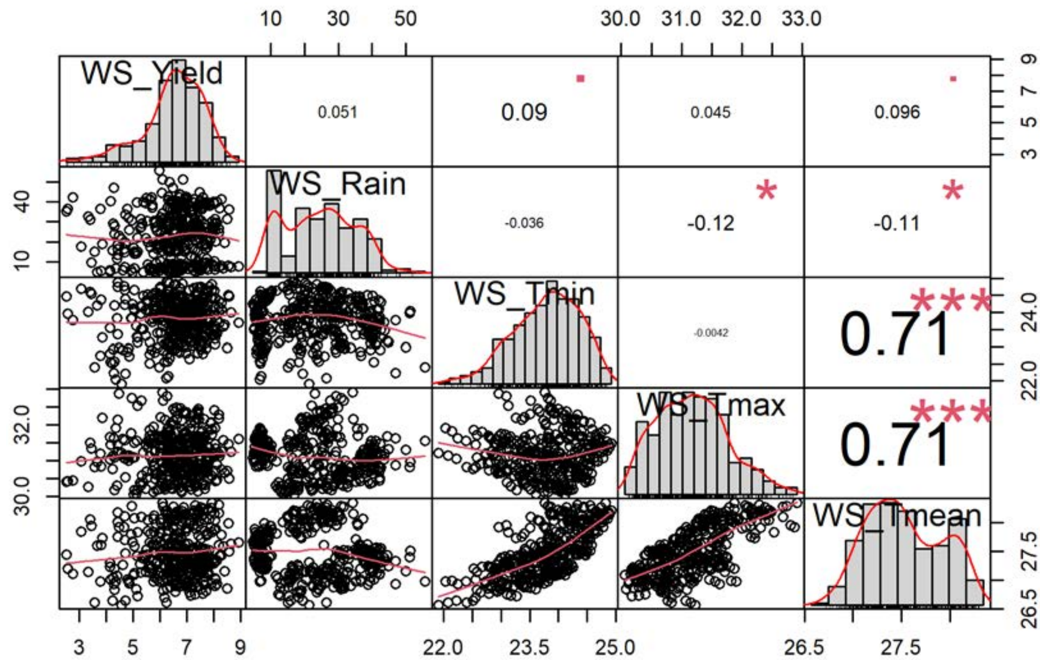


Figure 17. The distributions of rice yield (ton/ha), rainfall (mm), minimum, maximum, and average temperature for summer-autumn (SA), autumn-winter (AW), and winter-spring (WS) crops are shown on the diagonal. The bivariate scatter plots with a fitted line are displayed on the bottom of the diagonal. The values of the Pearson correlation coefficients with the significance level of 0.001, 0.01, 0.05, and 0.1 (*, **, *, and ▪) are indicated on the top of the diagonal.**

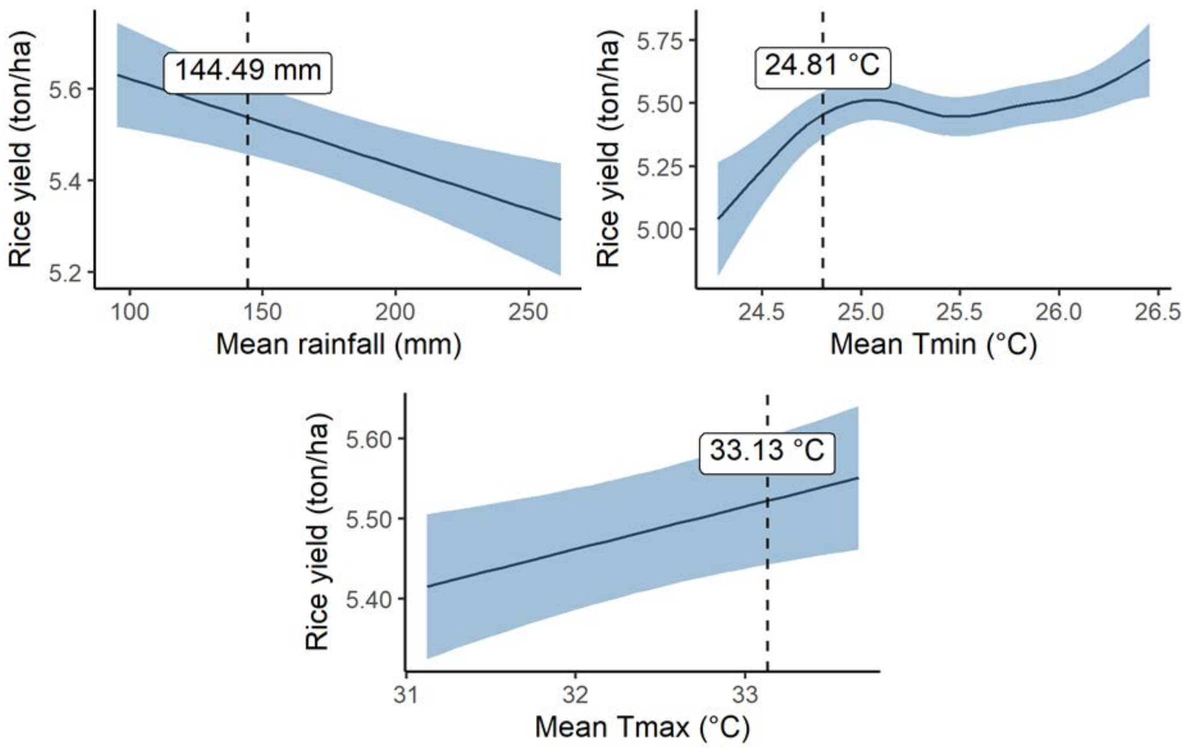


Figure 18. Summer-Autumn (SA) crop season.

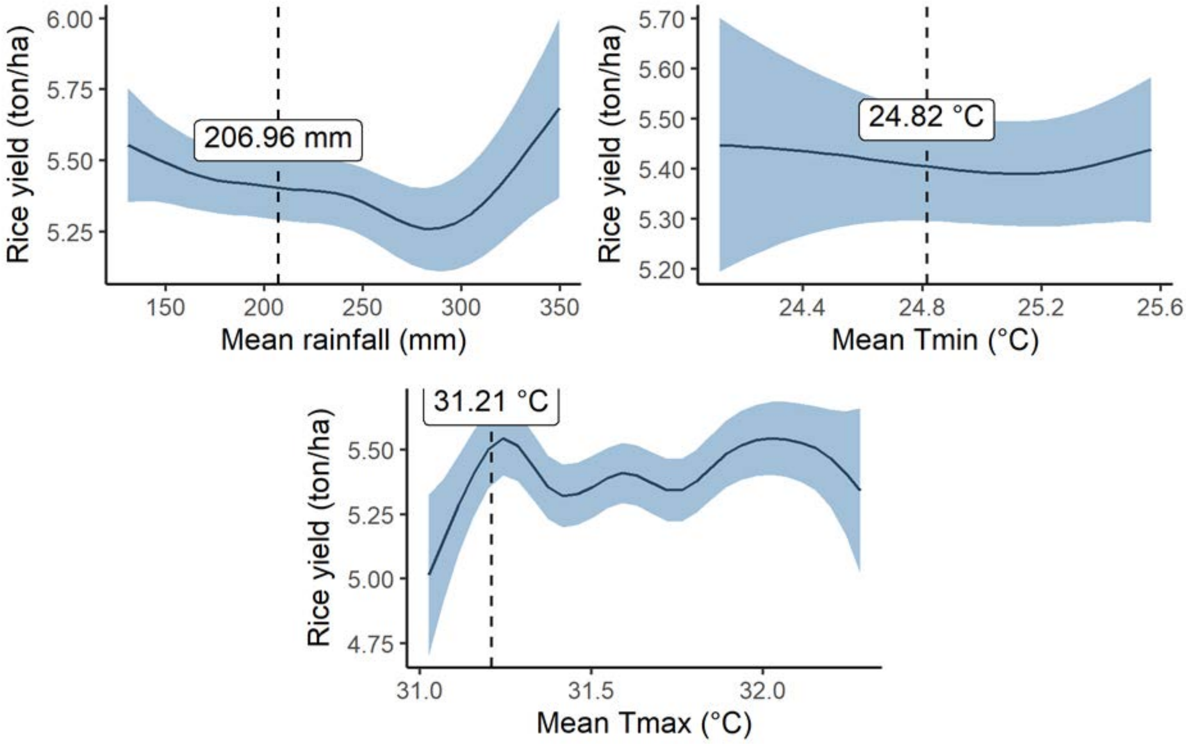


Figure 19. Autumn-Winter (AW) crop season.

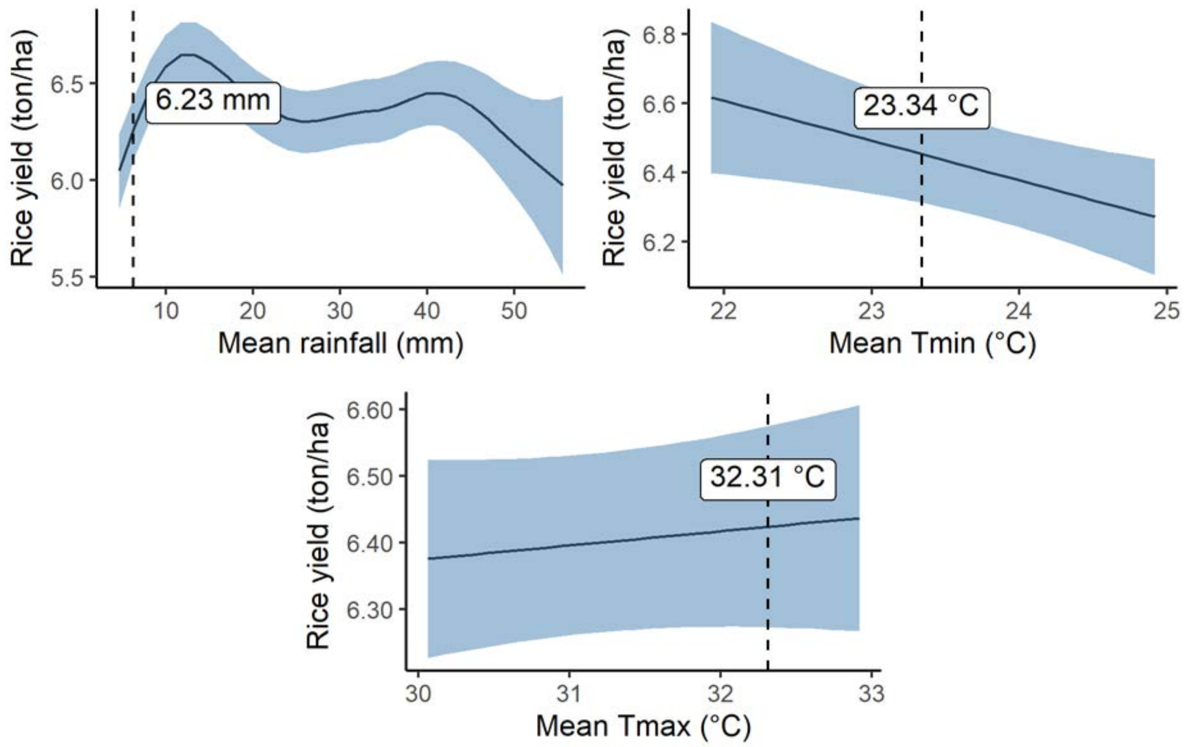


Figure 20. Winter-Spring (WS) crop season.

Season	*Predictor Variables*	*F*	*p-value*	*Adjusted R^2*	*GCV*	*Deviance explained (%)*
SA	Rainfall	2.963	< 0.1	0.74	0.20	80.5
	Tmin	1.736	> 0.1	0.75	0.20	81.1
	Tmax	1.730	> 0.1	0.74	0.20	80.7
AW	Rainfall	1.055	> 0.1	0.74	0.32	81.2
	Tmin	0.115	> 0.1	0.74	0.32	80.9
	Tmax	1.000	> 0.1	0.74	0.32	81.7
WS	Rainfall	2.087	< 0.05	0.76	0.42	82.4
	Tmin	1.590	> 0.1	0.75	0.44	81.0
	Tmax	0.134	> 0.1	0.74	0.44	80.9

Table 5. The GAM model outputs.

GCV: generalized cross validation score can be taken as an estimate of the mean square prediction error based on a leave-one-out cross validation estimation process, with lower being better.

Flexible temperature-binning analyses

Variable	**Mean**	**SD**	**Min**	**Max**
Temperature (°C)				
WS season	26.66	1.64	10.30	30.30
SA season	28.23	1.35	14.40	44.80
AW season	27.78	1.19	18.90	36.80
Cultivated area (hectare)				
WS season	2190.83	2900.65	46.40	18381.64
SA season	7338.50	9377.99	2.55	66482.45
AW season	3966.28	5579.06	1.04	36691.17
Yield per hectare (ton/hectare)				
WS season	6.00	2.14	2.56	8.57
SA season	5.20	1.65	2.92	16.48
AW season	4.46	2.31	1.91	7.44

Table 6. Descriptive statistics of main variables

Descriptive statistics of the key variables are included in Table 2. This table shows that the minimum temperature is 10.3°C in the WS season and the maximum temperature is 44.8°C in the SA season, completely corresponding to the VMD's weather characteristics where colder days usually take place in December or January (the onset of the WS season) while hotter days are almost always observed in April (the early period of the SA season). Further more, this table also reveals that the average rive cultivated area per district in the VMD in WS, SA and AW season are 2190.83 ha, 7338.50 ha and 3966.28 ha, respectively. The average rice yield is highest in WS season with 6.00 tons per hectare while this figure is 5.20 tons and 4.46 tons per hectare for SA and AW season, respectively.

Variable	WS	SA	AW	Total area
Temperature	-796.0128***	-69.37416	-1593.242*	-617.4819***
	(207.0375)	(552.6576)	(859.6013)	(145.6742)
Rainfall	65.3818	419.5616***	-68.38864	123.9225***
	(123.3117)	(150.6791)	(91.69256)	(45.23195)
Constant	23364.15***	6985.428	48830.44**	30441.76***
	(5583.941)	(15498.35)	(23812.76)	(4014.379)

Table 7. Estimating results of equation (3)

Notes: Standard errors in parentheses; * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Source: Authors' calculation.

The results in table 3 indicate the impact of temperature and precipitation, two significant factors of climate conditions on rice-cultivated area. The results reveal that increases in temperatures will decrease the cultivated area in WS season and AW season as well as the total yield of rice whereas increases in precipitation are beneficial to rice production in SA season. In particular, per 1°C increase in temperature would lead to reducing the cultivated area by 796 ha and 1593.2 ha in WS and AW season, respectively. However, increasing precipitation level in SA season will increase the cultivated area by 419.6 ha.

Variable	Winter-Spring	Summer-Autumn	Autumn-Winter
temp	1.161127	19.38928	45.54853
	(1.735844)	(20.69756)	(62.50659)
Precip	-0.0441016	0.0677765	-0.3759638
	(0.1504544)	(0.3899873)	(0.4211331)
$temp^2$	-0.0270052	-0.341608	-0.81527
	(0.0332304)	(0.3640948)	(1.122786)

$precip^2$	-0.0018162	-0.0042559	0.0104714
	(0.0124775)	(0.0281796)	(0.0232687)
Constant	-5.671709	-270.0756	-629.4259
	(22.79125)	(294.0658)	(869.1844)

Table 8. Estimating results of equation (4)

Notes: Standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Source: Authors' calculation.

Table 9 shows the impact of weather on crops by regressing yields on average growing season temperature and precipitation. However, the results suggest that by applying average values of climate variables for the growing season, we fail to find evidence about the relationship between climate change and rice production in the VMD.

Variable	Winter-Spring	Summer-Autumn	Autumn-Winter
≤ 20˚C	0.0150981	-1.837085	-1.059045
	(0.0283342)	(6.230424)	(2.636235)
20˚C - 22˚C	0.0170836	-3.525504	3.182886***
	(0.0357309)	(12.29859)	(1.164553)
22˚C - 24˚C	0.0468981**	-0.2665477	1.01315
	(0.0231435)	(0.4033623)	(0.7187382)
24˚C - 26˚C	0.0088493	-0.0249674	-0.0508854
	(0.0122856)	(0.0429082)	(0.0284973)
26˚C - 28˚C			
28˚C - 30˚C	0.0094239	0.0100137	-0.0062929
	(0.0140901)	(0.0089472)	(0.0112826)
30˚C - 32˚C	0.4083063	-0.0084869	-0.0264654
	(0.2531602)	(0.0082836)	(0.0612581)
32˚C - 34˚C		-2.632879	0.4903687
		(9.241081)	(0.3343631)
34˚C - 36˚C		3.034828	-4.983941***
		(11.27697)	(1.622335)
≥ 36˚C		-0.0093591	-8.301022***

		(0.6275269)	(2.664097)
Rainfall	-0.1677832	0.0797329	-0.2919069
	(0.1078141)	(0.0954635)	(0.0905385)
Constant	5.880024***	6.340441	50.31044 ***
	(0.4736752)	(6.2547)	(13.96415)

Table 9. Estimating results of equation (5)

Notes: Standard errors in parentheses; * p<0.1, ** p<0.05, *** p<0.01

Source: Authors' calculation.

The results in table 9 reveal that temperature of 20-22°C and 22-24°C is beneficial to crops for AW season and WS season, respectively while all temperatures above 34^0C are harmful to rice production in AW season. Specifically, all else equal, an additional day in the 20-22° C bin increase rice yields per hectare in AW by 3.18 ton/ha while an additional day with average temperatures of 22-24 °C increases rice yields by 0.05 tons/ha for WS season. The coefficient of 34-36° C bin and ≥ 36˚C shows that heat-induced losses are larger for higher temperatures. In particular, VMK is exposed to one more day in 34-36° bin led to a loss of 4.98 tons/ha while the loss increases to 8.3 tons/ha for temperatures above 36°C.

6. VietSCO Capacity Building Activities

Overview of CB activity – summary report stating how many people from which organisations were trained and short statement of outcome / feedback.

A series of SAR training sessions were held in November 2021 to address Capacity requests from the Vietnamese partners.The training is described below.

VIETSCO SAR Training Agenda 4-18 November 2021

1. Topic: Introduction to SAR remote sensing - applications to rice monitoring and flood monitoring

Content: The objective is to initiate the trainees to the use of SAR data. The program comprises lectures and practical exercises. The emphasis of the lectures will be on the understanding of SAR data and on the preprocessing operations specific to SAR data, required for data exploitation for rice and flood monitoring. The practical sessions include the following: Access to Sentinel-1 SAR data, SAR preprocessing (co-registered and geocoded, speckle filtering), Analysis of data time series, Interpretation, and derivation of indicators for applications (rice monitoring, surface water).

Software and material **:**

- QGIS, Orfeo Toolbox, Python, SNAP, all open-source software.

- Time series of Sentinel-1 over selected a selected region in Vietnam for practical part will be provided.The trainee's laptop can be used for the exercise. Software and data will be copied via USB.

2. Participants:

Participants from NRSD (7), VNSC (2), HUST (2).

Cf. List of participants

3. Trainers:

From CESBIO/CNES/ GLOBEO: Thierry Koleck, Hoa Phan, Trang Le, Alexandre Bouvet, Stéphane Mermoz, Thuy Le Toan

4. Draft agenda

Online via Zoom

https://univ-tlse3-fr.zoom.us/j/97396644261

Date: Nov. 04, Nov. 10, Nov. 15, Nov 18 , 2021
Time : 15pm-18pm Hanoi time (9am - 12am Paris time)

- Day 1 - 04/11/2021 (3h): Introduction to SAR remote sensing - Physical content of SAR data - How to access data portal of Sentinel-1 and open softwares (SNAP, QGIS).
- Day 2 - 10/11/2021 (3h): - Statistical properties of SAR images (everything related to speckle and how to filter its effect..) - Preprocessing steps (Pre- processing: calibration, geocoding, filtering,..)
- Day 3 - 15/11/2021 (3h): Rice monitoring (Theory and Practicals)
- Day 4 - 18/11/2021 (3h): Flood monitoring (Theory and Practicals)

Time		Content	Trainers
Day 1 **04/11/2021** **15pm - 18pm**	15:00 – 15:15 – 17 :00 17:10 - 18:00	- **Introduction** - Round table - **Lectures**: Introduction to SAR remote sensing - **Lectures**: Physical content of SAR data (understand characteristics of land surfaces backscatter- rice and water surfaces in SAR data) - Short break - **Lectures**: Sentinel-1 system & How to access data portal of Sentinel-1 and open softwares (SNAP, QGIS). **Homework**: download 1 Sentinel-1 image of their choice (ROI), install the softwares	All **Thuy Le Toan** **Thierry Koleck**
Day 2 **10/11/2021** **15pm - 18pm**	15:00 – 15:30 15:30 - 18:00	- **Lectures**: Statistical properties of SAR images (everything related to speckle and how to filter its effect..) - **Practical**: Pre-processing steps (Pre-processing: ROI extraction, calibration, geocoding, filtering,.. with SNAP) - Time series information extraction with QGIS, Back scattering analysis, Calculation of temporal change **Homework:** image preprocessing with 5 S1 images time series of their choice	**Thierry Koleck** **Alexandre Bouvet**, Stéphane Mermoz, Hoa Phan, Trang Le
Day 3 **15/11/2021** **15pm - 18pm**	15:00 – 15:30 15:30 – 16:00 16:00 – 18 :00	- Homework feedback/ questions and answers For Sentinel-1 image preprocessing, time series extraction... **- Lectures**: Rice monitoring - **Practical**: Exercises on Rice monitoring **Homework**: Rice monitoring	All **Hoa Phan**, Thuy Le Toan, Alexandre Bouvet **Alexandre Bouvet**, Hoa Phan

Day 4 **18/11/2021** **15pm - 18pm**	15:00 – 15:30 15:30 - 16:00 – 17 :30 18/00	- Homework feedback/ questions and answers For rice monitoring **- Lectures**: Flood monitoring - **Practical**: Exercises on Flood monitoring - Closing remarks	All ***Trang Le***, Thuy Le Toan, Alexandre Bouvet, Hoa Phan, Stéphane Mermoz All

7. VietSCO Dissemination – The VietSCO Platform

The main characteristics of the VietSCO platform have been described in the VietSCO platform specification document submitted in December 2021.

The data ingested in the platform include the maps derived in the frame of the VietSCO project (see Table 10), background images, ancillary data and statistical data computed at various spatial scales. Only the VietSCO products described as "operational products" in the User Requirements Document, i.e., resulting from processing chains dedicated to VietSCO that provide systematic and automatic results, in addition to salt intrusion maps, are shown in the platform.

Table 10. VietSCO operational products that feed the webGIS platform

Category	Name	Description
VM-Rice	SR Map	Seasonal rice maps
V-ARRO	FE Map	Flood extent map –flood extent and % district affected based on S-1
V-ARRO	RR Map	Rice recovery maps at S-1 acquisition date
V-ARRO	FD Map	Flood duration map – extent of flood over time based on S-1
V-ARRO	RAF Map	Rice crops affected by flood map – areas planted with rice affected
VM-Rice	-	Projection of rice under various climate climate change scenarii

The base maps are the background images of the platform and are of importance in webGIS in general. These data are summarized in Table 11 and include the Sentinel-2 cloudless yearly mosaics and the Planet monthly mosaics.

Table 11. Base maps that will feed the VietSCO webGIS platform

Name	Description	Format	Access/ Delivery
Sentinel-2 Cloudless	Provinces delineation	Shape file	https://s2maps.eu/
Planet	Monthly mosaics over the tropics	Raster, Flux	https://www.planet.com/nicfi/

Ancillary data are also mandatory within the webGIS platform to make the maps understandable. These data are summarized in Table 12 and include classic administrative areas related to the country and provinces borders.

Table 12. Ancillary data that will feed the VietSCO webGIS platform

Name	Description	Format	Access/ Delivery
Administrative areas 0	Border of Vietnam	Shape file	https://data.apps.fao.org/map/catalog/static/search?format=shapefile
Administrative areas 1	Provinces delineation	Shape file	https://www.diva-gis.org/gdata

The platform is composed of:

- The webGIS,
- A general and a technical description of the maps,
- A description of how to download the data,
- A blog tab.

Within the maps description tab, a general description of the project is first provided, followed by a technical description of the maps. The technical description gives an overview of the methods that are used to derive the maps, the evolutions of the methods since their publication within peer-reviewed scientific journals, and in particular the main technical characteristics of the maps, such as the spatial and temporal resolutions, the minimum mapping unit, the projection, etc.

In the download tab are listed the products to be downloaded. Hyperlinks to the GeoTIFF files and Web Map Services are available. The latter allows to provide a direct link to the images that are used in the VietSCO platform, which is the most convenient option for easily browsing the map and producing cartographic products.

Other information are detailed in the VietSCO platform, such as the license associated to the data, the citations to be used when using the data in published studies, a data user guide for a description of all of the datasets and details on how to use the data, and the contact for any feedbacks on the VietSCO products.

The website is available in Vietnamese and in English. The website has been distributed to some users (e.g., VNSC) during the development phase to get feedbacks.

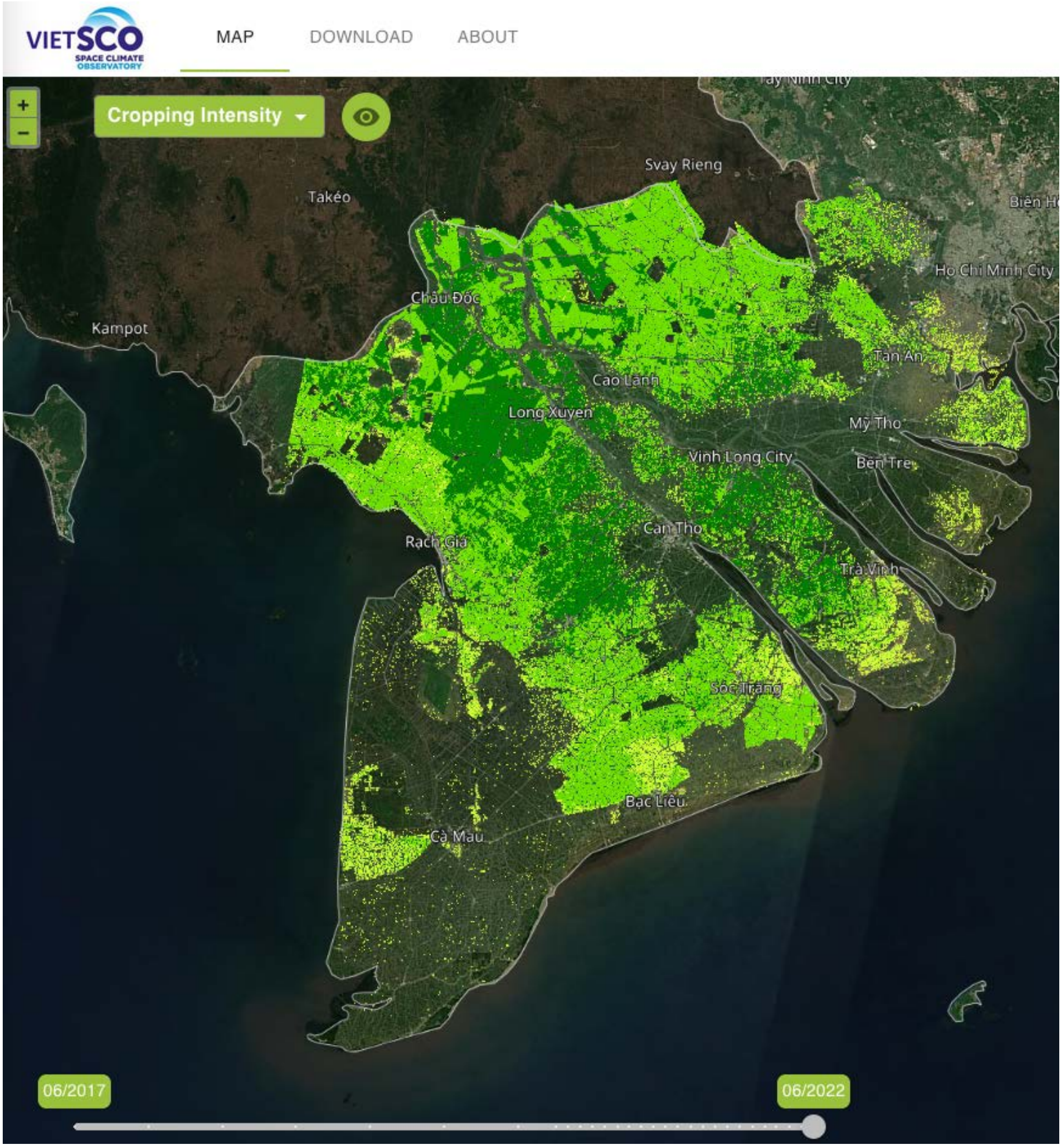
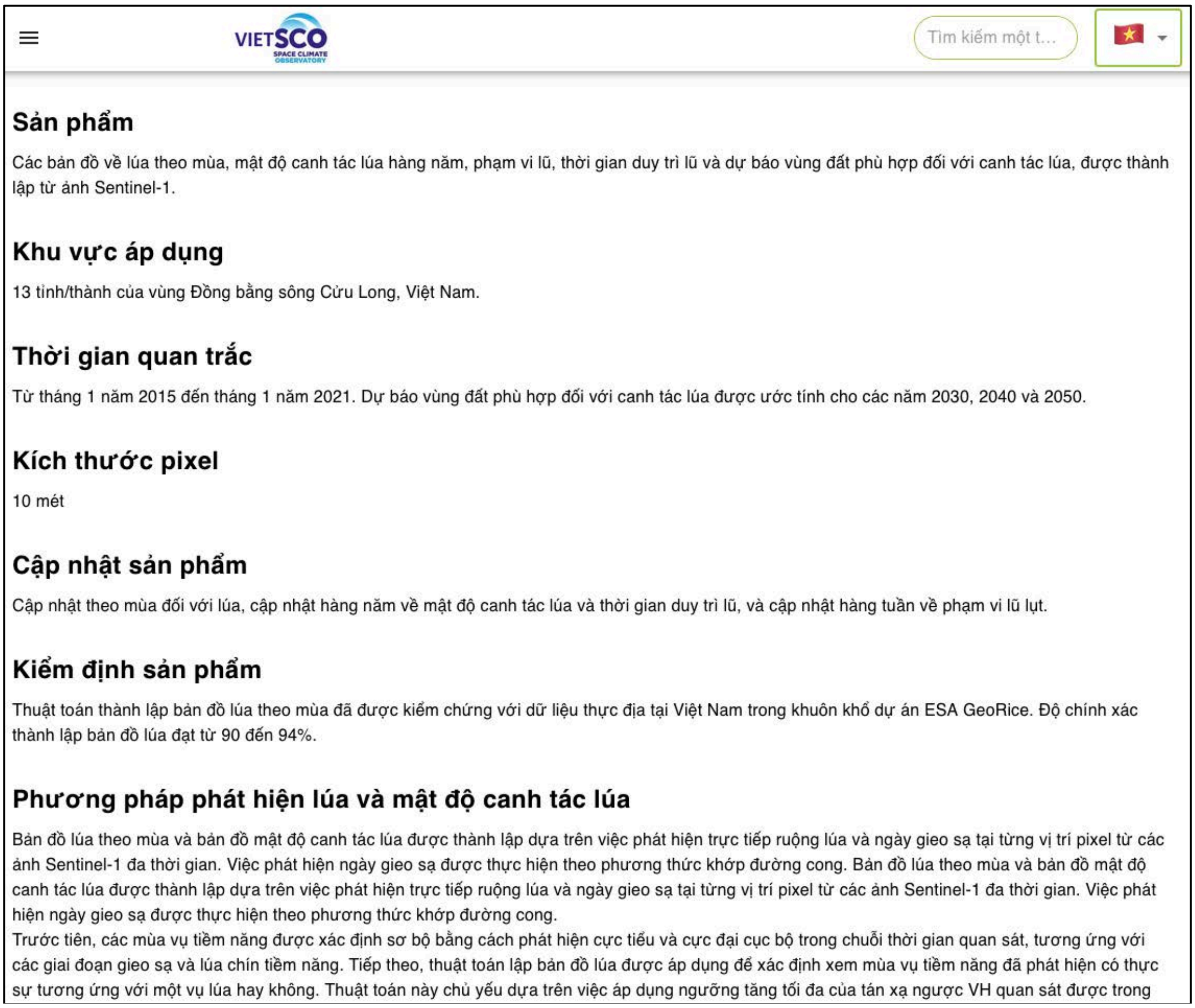


Figure 21. Printscreen of the VietSCO platform, showing annual rice crop density.



Tìm kiếm một t...

Sản phẩm

Các bản đồ về lúa theo mùa, mật độ canh tác lúa hàng năm, phạm vi lũ, thời gian duy trì lũ và dự báo vùng đất phù hợp đối với canh tác lúa, được thành lập từ ảnh Sentinel-1.

Khu vực áp dụng

13 tỉnh/thành của vùng Đồng bằng sông Cửu Long, Việt Nam.

Thời gian quan trắc

Từ tháng 1 năm 2015 đến tháng 1 năm 2021. Dự báo vùng đất phù hợp đối với canh tác lúa được ước tính cho các năm 2030, 2040 và 2050.

Kích thước pixel

10 mét

Cập nhật sản phẩm

Cập nhật theo mùa đối với lúa, cập nhật hàng năm về mật độ canh tác lúa và thời gian duy trì lũ, và cập nhật hàng tuần về phạm vi lũ lụt.

Kiểm định sản phẩm

Thuật toán thành lập bản đồ lúa theo mùa đã được kiểm chứng với dữ liệu thực địa tại Việt Nam trong khuôn khổ dự án ESA GeoRice. Độ chính xác thành lập bản đồ lúa đạt từ 90 đến 94%.

Phương pháp phát hiện lúa và mật độ canh tác lúa

Bản đồ lúa theo mùa và bản đồ mật độ canh tác lúa được thành lập dựa trên việc phát hiện trực tiếp ruộng lúa và ngày gieo sạ tại từng vị trí pixel từ các ảnh Sentinel-1 đa thời gian. Việc phát hiện ngày gieo sạ được thực hiện theo phương thức khớp đường cong. Bản đồ lúa theo mùa và bản đồ mật độ canh tác lúa được thành lập dựa trên việc phát hiện trực tiếp ruộng lúa và ngày gieo sạ tại từng vị trí pixel từ các ảnh Sentinel-1 đa thời gian. Việc phát hiện ngày gieo sạ được thực hiện theo phương thức khớp đường cong.

Trước tiên, các mùa vụ tiềm năng được xác định sơ bộ bằng cách phát hiện cực tiểu và cực đại cục bộ trong chuỗi thời gian quan sát, tương ứng với các giai đoạn gieo sạ và lúa chín tiềm năng. Tiếp theo, thuật toán lập bản đồ lúa được áp dụng để xác định xem mùa vụ tiềm năng đã phát hiện có thực sự tương ứng với một vụ lúa hay không. Thuật toán này chủ yếu dựa trên việc áp dụng ngưỡng tăng tối đa của tán xạ ngược VH quan sát được trong

Figure 22. Printscreen of the VietSCO platform, showing the 'About' tab

8. Conclusions and Plans for Phase 2

VietSCO users have expressed satisfaction at the results of the first Phase. There are however several outstanding issues to be resolved in order to increase the relevance of the collaboration.

These issues are addressed below in the recommendations for phase 2:

- Augmented transfer of capacity
  While the users expressed satisfaction at the capacity training provided in relation to SAR data usage, a broadly shared view was that more work is required to transfer effective exploitation capacity to the users, by installing software and tools at their premises and ensuring they are enabled and empowered as VietSCO users.

- Extension of VietSCO to new thematic areas
  While rice cultivation and changes to cultivation practices are at the heart of the existing user community, several stakeholders indicated Phase 2 should address a broader community, including forestry, and coastal zone management.

- Tailored approach for each user community
  While the VietSCO platform was well received at the User Conference, it remains essentially a visualization tool and many users would like the ability to use shape files and other outputs of VietSCO in their own systems. A dedicated approach for each user is required to identify the systems they use and the approach for increased integration.

A phase 2 proposal is under development and will be circulated to partners in the fall timeframe.

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