

ADVANCING THE PHILIPPINES' CLIMATE CHANGE RESPONSE THROUGH DOST-ASTI'S SARWAIS PROJECT

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ABSTRACT: Spaceborne data has always been vital in disaster risk reduction and management efforts especially in disaster-prone areas. Since 2016, the Department of Science and Technology - Advanced Science and Technology Institute (DOST-ASTI) of the Philippines have used data from satellites to monitor disasters that are increasingly worsening because of climate change. In 2018, the Institute implemented the SARwAIS Project that acquired a 10% share on image tasking of NovaSAR-1, a low-cost S-Band Synthetic Aperture Radar (SAR) satellite developed and launched by UK's SSTL. This satellite is generally utilized to monitor the country's maritime domain. It has also been tasked to acquire images that are used to map potentially flooded areas, which are becoming more frequent due to climate change; and to map and monitor aquaculture structures, which, if left unregulated, may adversely affect blue carbon ecosystems. This project also allowed the country to gain free access to the satellite images of partner international space agencies, which are then used in monitoring areas in the country that are potentially prone to the effects of climate change. These efforts have substantially contributed to the achievement of Goal 13 of the Sustainable Development Goals which focuses on combating the effects of climate change.

1. INTRODUCTION

1.1 SAR Data and their Application to Disaster Response

As the most disaster-prone region in the world, the Asia-Pacific suffered from more than 2 million deaths from natural disasters over the past half century (UN ESCAP, 2021). The region faced the highest number of natural disasters in 2021 (Jaganmohan, 2022), with the Philippines ranking fifth on the list of countries with highest number of natural disasters, having faced 14 that year (Szmigiera, 2022).

Spaceborne data has been a useful tool for Disaster Risk Reduction and Management (DRRM) especially in the Asia-Pacific Region. Synthetic Aperture Radar (SAR) satellites are ideal resources for spaceborne data during disasters due to their capability to capture images day and night, and penetrate cloud cover, unlike optical satellites that are reliant on natural illumination from the sun and can be affected by clouds (Lê et al., 2022). Satellite images, especially SAR images, are frequently used in mapping out potentially flooded areas, which can provide high-accuracy information for the assessment of flood extent (Bhatt et al., 2013). In India, both SAR and optical satellite images were used to determine extent of inundation in districts surrounding two rivers during the monsoon month of August 2017 (Anusha & Bharathi, 2020). In Vietnam, image time series from Sentinel-1 were used to monitor flooding along the central coast of the country during the rainy season of 2017 and 2018 (Lê et al., 2022).

In the Philippines, the DOST-ASTI together with the University of the Philippines Diliman's College of Engineering (UP COE) and National Institute of Geological Sciences (UP NIGS) studied the use of geospatial data such as imagery from ALOS AVNIR-2 to monitor and forecast flood along Marikina River, an area very prone to flooding (Santillan et al., 2013). On the other hand, the Nationwide Operational Assessment of Hazards (Project NOAH) used airborne Interferometric SAR data together with Light Detection and Ranging (LiDAR) data, weather-related sensors, Digital Terrain Models (DTM), data from weather satellites, etc., to create hazard maps and early-warning systems for disasters disseminated to the public (Lagmay et al., 2017).

1.2 Coastal Flooding, Sea Level Rise, and Land subsidence

The risk of flooding in coastal areas increases due to the combined effects of climate change and land subsidence (Chen, C.N., and Samkele T., 2018; Wang, H.W., et al., 2018). Global warming is causing sea level rise and frequent extreme

weather events that can bring more excessive rainfall. Land subsidence, on the other hand, causes the ground to decrease in those areas, thus making them even more vulnerable to flooding. In the Philippines, specifically in areas surrounding Manila Bay, inundation is already frequent. The recognized cause of this phenomena is the combined effects of sea level rise and land subsidence (Rodolfo, K. S., and Siringan F., 2006).

Several studies have determined that compared to sea level rise, land subsidence contributes higher risk for deeper and more prolonged flooding in coastal areas, and that they should be addressed with greater importance and urgency in order to significantly minimize the overall risk of inundation (Rodolfo, K. S., and Siringan F., 2006; Chen, C.N., and Samkele T., 2018; Wang, H.W., et. al., 2018). Elevated rates of land subsidence can be attributed to anthropogenic activities, primarily excessive ground water extraction. Strict implementation of mitigation measures can help in significantly minimizing the overall risk of inundation of affected areas, though it should be noted that the impact of sea level rise will persist (Rodolfo, K. S., and Siringan F., 2006).

Monitoring land subsidence and determining trends in their rates can help assess the overall effectiveness of the implementation of mitigation measures. Sustained subsidence rates can imply the loose, if not lack of, implementation of relevant mitigation measures. Meanwhile, reduction in subsidence rates may imply effective implementation, or cessation of the anthropogenic activities due to apparent depletion of the resources being extracted. Regularly acquired radar images are effective tools for mapping and monitoring land subsidence since they can be used to determine accurate and up-to-date information about any on-going land subsidence over large areas (Eco RC, et al., 2020).

1.3 Blue Carbon Ecosystems, Climate Change, and Aquaculture Structures

Blue carbon refers to carbon being sequestered or captured by marine ecosystems. Sea grasses, mangroves, and salt marshes, which can generally be referred to as blue carbon ecosystems, can absorb and hold carbon at much faster rates than the upland forests (NOAA, 2023). With such capability, these ecosystems can be harnessed to capture and hold more carbon from the atmosphere, and the conservation, protection, and restoration of these ecosystems can be part of climate change mitigation strategies of the country (Hilmi, Nathalie, et al., 2021). Failure to protect and conserve them can lead to the release of the enormous amount of carbon into the atmosphere, and the loss of diminished capacity as carbon sinks, both of which can contribute to climate change (NOAA, 2023).

Development and operations of aquaculture structures have been used to address food security concerns in the country, accounting for around 50% of the total fisheries production in the country by 2015 (Primavera, J.H., 2006; Guerrero R., 2017). However, these structures have adverse effects on blue carbon ecosystems, including destruction of mangrove forests and seagrass meadows. In the Philippines, the original mangrove forest cover has declined by about 50% due to their conversion into brackish or estuarine fishponds (Mariano, H., et. al., 2022). With such loss of mangrove forest cover, the country has a substantially reduced carbon sink capacity. Hence, it is crucial that the remaining mangrove forest cover be saved from further destruction. Furthermore, any abandoned fishponds should be identified due to their strong potential as sites of mangrove forest restoration, which in turn can help increase or restore the country's carbon sink capacity (Mariano, H., et. al., 2022).

Aquaculture structures are prone to the effects of severe weather disturbances. For example, strong winds and waves brought by tropical cyclones can damage or destroy them. With climate change, these weather disturbances are now becoming more frequent and severe. Moreover, the on-going sea level rise also poses a significant threat of breaches or breakage on the dikes of fishponds, which could make operations more costly. Global warming can also cause the water temperature to rise, which can adversely affect the ideal water conditions for fish production. This means that the sustainability of aquaculture structure operations can be adversely impacted by climate change (Guerrero R., 2017).

Acquiring up-to-date inventory of aquaculture structures is a crucial step in addressing and mitigating the adverse effects of these structures to the blue carbon ecosystems of the country. Up-to-date inventory of fishponds and their status provide important inputs for programs aimed at reverting abandoned or disused fishponds into mangrove forest (Ferrer, A.J.G., et. al., 2016). Determining the scale and extent of aquaculture operations in the country is crucial in the formulation of policies for the adoption of carbon-neutral operations of such structures. Regular mapping and monitoring of aquaculture structures are also important in assessing and quantifying the adverse impacts of climate change on these structures as well as in creating strategies that will make the operations of structure more climate change resilient.

1.4 The Philippines and SDG 13

The Philippines has been supporting UN's sustainable development goals (SDGs) and all its targets since 2015 (National Economic Development Authority, n.d.). One particular focus is SDG 13 which centers on addressing the impacts of climate change. SDG 13 aims to strengthen the world's response to the climate crisis through mitigation of climate change's effects, raising global awareness and integrating it into a country's policymaking (United Nations, n.d.).

Alongside SDG 13 is the Sendai Framework for Disaster Risk Reduction endorsed by the United Nations General Assembly in 2015 that aims to substantially reduce losses due to disasters (United Nations Office for Disaster Risk Reduction, n.d.).

Several laws and policies have been enacted and established in the Philippines to address its need for a rapid and effective disaster response. Republic Act 10121 or the Philippine Disaster Risk Reduction and Management Act of 2010 was enacted to strengthen the country's capacity to address disaster risk reduction and management including climate change impacts. The same law also established a coordination and policymaking body, the National Disaster Risk Reduction and Management Council (NDRRMC), formerly National Disaster Coordinating Council, and developed a dynamic framework and management plan for the country's approach to disasters. Since its establishment, the council has been the main governing body for disasters in the country, giving extensive reports and directives during disasters.

Recognizing the advantages of space science and technology in relation to climate change, the country started investing in this sector by the early 2010s. Specifically, the DOST-ASTI, in cooperation with the University of the Philippines Diliman, built the groundwork for the country's own space science and technology infrastructure. Some of these initiatives include the development of the country's own earth observation satellites, such as the Diwata-1 and Diwata-2, and the establishment of the Philippine Earth Data Resource and Observation (PEDRO) Center, a network of ground receiving stations (GRS) used for tasking and receiving satellite imageries. The institute has also established its Computing and Archiving Research Environment (COARE) Facility, which provides High Performance Computing (HPC) services that can help process large satellite datasets much faster. It has also implemented research projects like the Remote Sensing and Data Science Help Desk or the DATOS, which explored the use of satellite datasets, several of which were acquired through the PEDRO Center, for various applications such as environmental monitoring, terrestrial and maritime surveillance, and disaster risk management. With the establishment and implementation of these services, the country, through DOST-ASTI, has developed operational workflows that can address the country's need for spaceborne data in a matter of hours or days, especially in high-pressure situations such as disasters.

1.5 The SARwAIS Project

In 2018, DOST-ASTI began implementing the Synthetic Aperture Radar and Automatic Identification System for Innovative Terrestrial Monitoring and Maritime Surveillance (SARwAIS) Project. This research project aims to explore the possible uses and applications of S-Band SAR images acquired by the NovaSAR-1 satellite. This satellite was developed, built, and launched last 2018 by the Surrey Satellite Technology Ltd (SSTL), an aerospace company based in the United Kingdom, with fundings acquired through their partnerships with institutions from countries like India, Australia, USA, and the Philippines through the SARwAIS Project of DOST-ASTI. Through this partnership, the country has acquired a 10% share of the imaging capacity of the NovaSAR-1 satellite, which translates to approximately two (2) minutes of imaging time or 81,600 km² per day. The image acquisition parameters of this satellite can be modified to fit with the requirements of their intended use. This satellite is integrated with the PEDRO Center, which allows the country to independently send image tasking commands, as well as download the acquired images through the DOST-ASTI.

Further, the SARwAIS Project developed the Surveillance, Identification, and Assessment using Satellites (SIYASAT) Portal as its image collection and planning system that makes tasking and acquiring data more accessible to the project's stakeholders. Through the project, maritime applications using SAR images and AIS datasets from the NovaSAR-1 satellite were developed, utilizing available outputs and workflows from the DATOS Project. With great potential and response to the products, the development of various terrain applications was also explored, starting with disaster response, especially during severe weather events.

1.6 Motivation

The achievement of SDG 13 or Climate Action in the Philippines faces challenges as the country is exposed to multiple natural disasters every year. The country's archipelagic state impedes the quality, logistics, and speed of disaster response, posing threats to resilience indicators and overall rehabilitation. This paper discusses the ways that the SARwAIS project was able to advance the country's Climate Action or SDG 13 using available earth observation datasets.

2. METHODOLOGY

2.1 Utilizing NovaSAR-1 Images for Rapid Potential Flood Mapping

The country experiences several severe weather events throughout the year, many of which cause flooding events that can affect many cities and municipalities. Such occurrences are expected to increase in terms of frequency and severity

due to climate change (NASA-JPL, 2023). Timely generation of potential flood maps is crucial to disaster response as it can provide responders with near real-time information and overview on the flooding situation on affected areas. To help address this, the DOST-ASTI developed an AI-based flood mapping workflow in 2019, which utilizes Sentinel-1 SAR images only (de la Cruz et al., 2020). Since its development and deployment, this workflow has been successful in providing potential flood maps to national government agencies relevant to disaster response. However, there are instances when no flood maps are generated due to unavailability of Sentinel-1 SAR images. To help address this gap in data availability for the generation of potential flood maps, the institute explored and capitalized on the potential of NovaSAR-1 SAR images for this purpose.

The SARwAIS team developed a general workflow for generating potential flood maps of the affected areas using NovaSAR-1 images. During severe weather events, the team determines first the availability of NovaSAR-1 for image acquisitions over affected areas, which is mainly dependent on the estimated orbit pass of the satellite during the target acquisition date, and the estimated extents of the swath based on the acquisition parameters (i.e., incidence angles, acquisition modes) that were initially considered as best for flood mapping especially in terms of coverage and spatial resolution. If the satellite is available on the target acquisition date and the estimated extent can substantially cover the target area, then an image acquisition task is submitted to SSTL for upload to the satellite. If the tasking is successfully uploaded, the satellite captures the images according to the provided acquisition parameters.

Once the captured images are successfully turned over to DOST-ASTI, the SARwAIS team pre-processes them into analysis-ready products (i.e., terrain-corrected, geocoded, and in decibel scale), and generates the potential flood maps using the threshold method. The team then assesses the reliability and accuracy of the generated maps. If the products are deemed as sufficiently reliable and accurate, then they are distributed to relevant government agencies and stakeholders. Figure 1 shows the summary of the general workflow employed by DOST-ASTI for rapid potential flood mapping using NovaSAR-1 images.

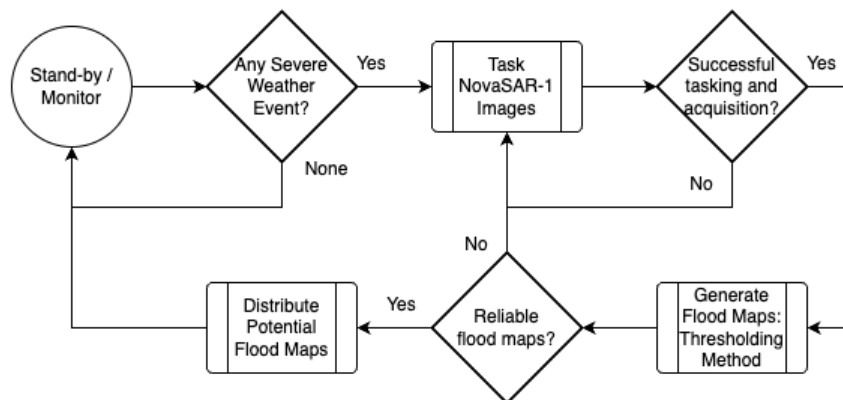


Figure 1. General workflow employed by DOST-ASTI's SARwAIS team when using NovaSAR-1 SAR images for potential flood mapping during severe weather events.

2.2 AI Technology for Mapping and Monitoring of Aquaculture Structures

Getting up-to-date inventory of existing aquaculture structures in the country is crucial to the monitoring and regulation of their operations especially in the aspect of environmental sustainability and climate change resilience. Regular mapping and monitoring can also help determine old and abandoned structures, especially fishponds, that can be reverted into mangrove forests. To support these efforts of government agencies mandated with the inventory of the country's aquaculture structures, DOST-ASTI, through the DATOS and SARwAIS teams, explored the use of artificial intelligence and satellite images.

In 2020, the Philippine Statistics Authority or PSA partnered with DOST-ASTI through the SARwAIS project for the implementation of the Artificial Intelligence for Census on Agriculture and Fisheries or AI4CAF Project by the year 2022. This collaborative research project aims to employ earth observation or remote sensing datasets, including NovaSAR-1 SAR images, and Artificial Intelligence or AI on the conduct of PSA's Census on Agriculture and Fisheries (DOST ASTI, 2021; Philippine Information Agency, 2023).

In this partnership, AI models for aquaculture structures like fishponds, fish pens, and fish cages were co-developed by the teams of the two agencies. DOST-ASTI, through the DATOS Project, and later, through the SARwAIS Project, trained several PSA personnel on the processes and workflows involving applications of AI on satellite images.

Afterwards, the two agencies proceeded with the AI models development. In this phase, the PSA team provided the AOIs for the target features, and the DOST-ASTI team subsequently provided the available NovaSAR-1 images as well as other available SAR images covering the given AOIs. PSA's team then digitized the desired features, which were used to generate the training datasets for the AI model of the target feature or aquaculture type. Once enough training datasets are available, the AI model training followed. The accuracy of the predictions of the generated target feature AI model prototype is then assessed. If the accuracy is unacceptable, retraining is done wherein more images are acquired and more training datasets are generated, which are used to help improve the AI model's accuracy. This process is repeated until the accuracy of the AI model is already acceptable. Once this is achieved, the AI model is already ready for deployment. Figure 2 shows the general workflow employed in the development of AI models for aquaculture structures.

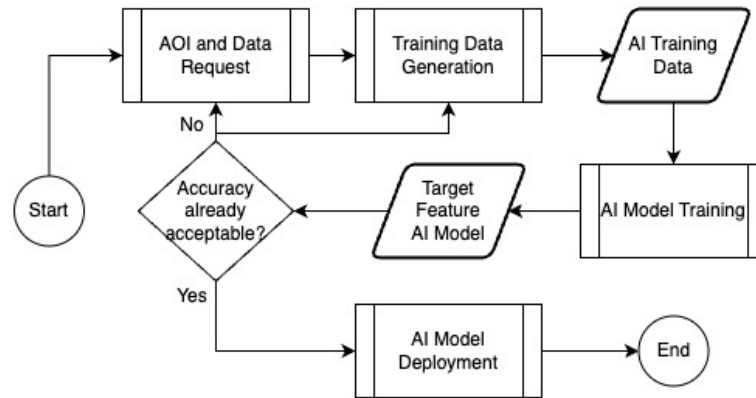


Figure 2. General workflow on aquaculture structure AI model development

2.3 Providing Data on Land Subsidence Trends in Areas Along Manila Bay

The frequent and often prolonged flooding in several coastal areas in Bulacan and Metro Manila are manifestations of the combined impact of climate-induced sea level rise and the on-going land subsidence in these areas. Moreover, on-going land subsidence that is induced or aggravated by excessive ground water extraction is considered to be the primary contributor to the enhanced flooding of these areas (Rodolfo, K. S., and Siringan F., 2006). Therefore, it is imperative to monitor these areas and generate up-to-date information on the extents and trends of the detected subsidence rates, which can then be provided to and used by national and local policy makers and stakeholders in crafting and implementing timely, relevant, and more appropriate land subsidence mitigation measures.

To help address the need to determine the current and most recent trends of land subsidence in Metro Manila and nearby provinces, DOST-ASTI, through DATOS and SARwAIS, utilized SAR images covering these areas in generating this information. Specifically, historical ALOS-2 SAR datasets acquired through a partnership with Japan Aerospace Exploration Agency (JAXA) were processed using PSInSAR technique. SARProz, a proprietary software specialized in executing the multitemporal SAR image analysis including PSInSAR, was used to generate products that provide info on the estimated velocity trends of identified permanent scatterers and estimated cumulative ground displacement within the input dataset's time frame.

3. DISCUSSIONS

3.1 Use of NovaSAR-1 SAR Images in Operational Rapid Flood Mapping

The SARwAIS team has successfully augmented the AI-based flood mapping algorithm by using the S-Band NovaSAR-1 images. Most of the tasking requests made during extreme or severe weather events were successfully uploaded, and the corresponding images were subsequently captured. Afterwards, successfully captured NovaSAR-1 images have also been processed to generate potential flood maps. In addition, since the start of the utilization of NovaSAR-1 images for flood extents mapping last 2021, there have been several instances when potential flood map products derived from NovaSAR-1 images has been successfully generated and distributed to relevant disaster response agencies. These products have also been published in DATOS' official social media accounts. Figure 3 shows a sample flood map generated from a NovaSAR-1 image. This map has been published in the DATOS Facebook pages and has also been distributed to relevant disaster response agencies.

Despite the success of team in utilizing NovaSAR-1 images for potential flood mapping, it should still be noted that the team has still encountered several unsuccessful attempts. There were times when the image acquisition tasks were not successfully uploaded to the satellite, usually due to conflicts with the schedule of submitted tasks of other partner countries or scheduled down time of the satellite. There are also several instances when the quality of the captured image was simply considered as not acceptable due to reduced contrast between the water and non-water pixels. Whenever these issues happen, the team reassess the availability of the satellite, and makes another tasking request if still necessary.

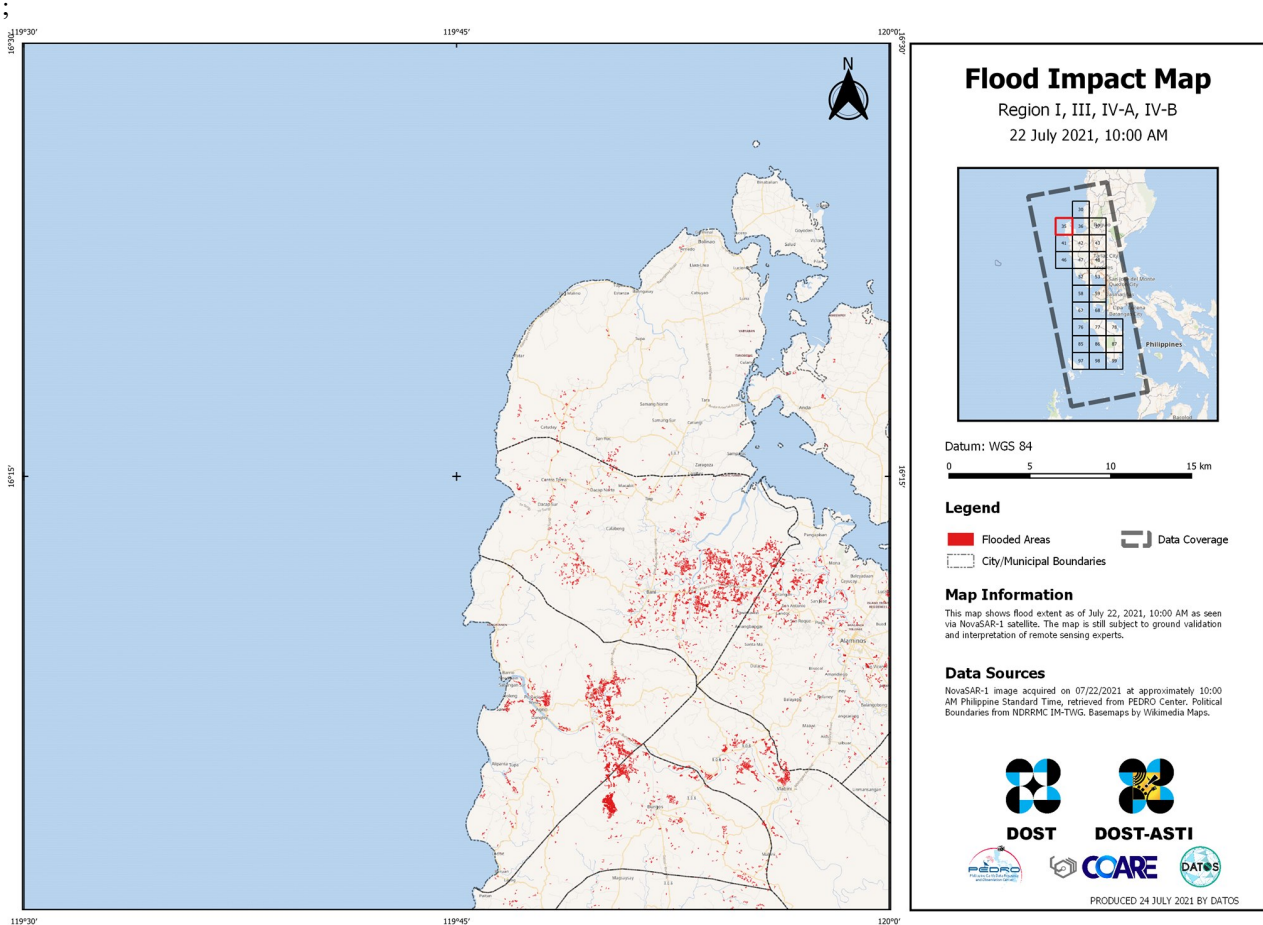


Figure 3. Sample flood map derived from a NovaSAR-1 image dated 22 July 2021. This map has already been published in the DATOS Facebook page.

The timeliness of the flood maps generated from NovaSAR-1 images is dependent on how soon SSTL can process and deliver the satellite images. There have been instances when SSTL was able to provide some only several days after they were acquired. Whenever this happens, the flood maps derived from these images become irrelevant as they no longer provide timely information on the potential flooding of the affected areas. To address this, the team worked on the integration of the satellite to the PEDRO Center, which allows direct download of images to generate the desired products in a much shorter period.

3.2 Nationwide Aquaculture Structures Mapping and Monitoring

The collaborative efforts of PSA and DOST-ASTI since 2020 has led to the successful development of several AI models for fishponds, fish pens, and fish cages. Figure 3 is a map showing the aquaculture structures as predicted by the developed AI models on the NovaSAR-image covering a portion of Bolinao and Anda in the province of Pangasinan. These sites have high concentration of aquaculture structures, which has been ideal for the training and prediction of the AI models being developed.

Through the support of DOST-ASTI's SARwAIS team and other former staff of the project who eventually transferred to the Philippine Space Agency or PhilSA, the PSA became equipped with the knowledge and technical capabilities on the applications of AI on earth observation datasets, particularly NovaSAR-1 images. The introduction of AI and remote

sensing complimented their other census methodologies, thus enabling them to conduct more frequent and more reliable inventory of the aquaculture structures.

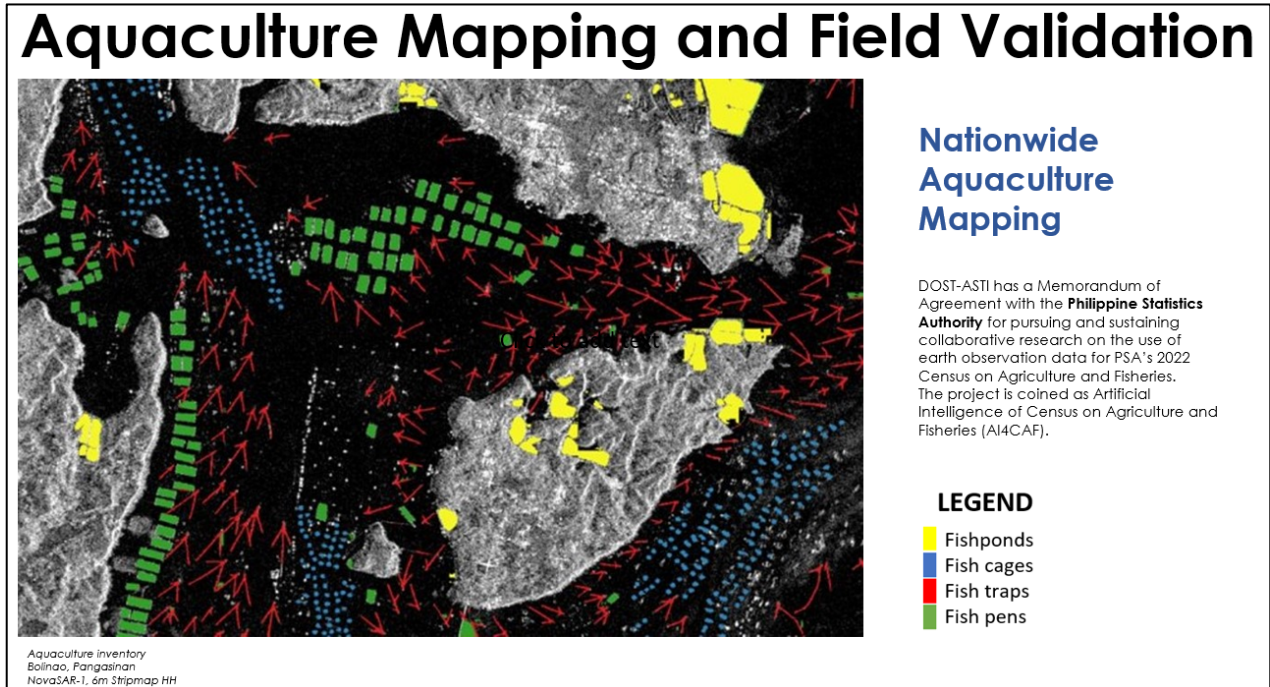


Figure 4. Aquaculture structures as identified by the AI models co-developed by the teams of SARwAIS and PSA. The NovaSAR-1 image used covers a portion of Bolinao and Anda.

3.3 Generated Land Subsidence Maps

Using PSInSAR technique that was applied to ALOS-2 images acquired from June 2016 to May 2022, the SARwAIS team was able to generate cumulative displacement maps and displacement velocity trends in Metro Manila and the nearby provinces of Bulacan, Pampanga, Cavite, and Rizal. Figure 5 shows the estimated cumulative displacement (values range from -1000 to +1000mm as indicated by the red to blue color ramp) in Metro Manila and the nearby provinces. These values are computed from June 2016 to May 2022. These outputs implies that the land subsidence in these areas that was detected in previous studies are still on-going.

By generating the ground deformation maps, the SARwAIS team is providing the mandated and relevant agencies with actionable data and information on the current trends of the ground deformation in the affected areas, which can be translated into appropriate mitigation measures. The DOST-ASTI, through the SARwAIS team, has on-going collaboration with other government agencies like the Philippine Institute of Volcanology and Seismology (PHIVOLCS) and PhilSA for the continuous monitoring of these areas. The team also conducted training sessions aimed at sharing with the partner agencies the technologies being used to generate these products, which can support or complement their respective mandates.

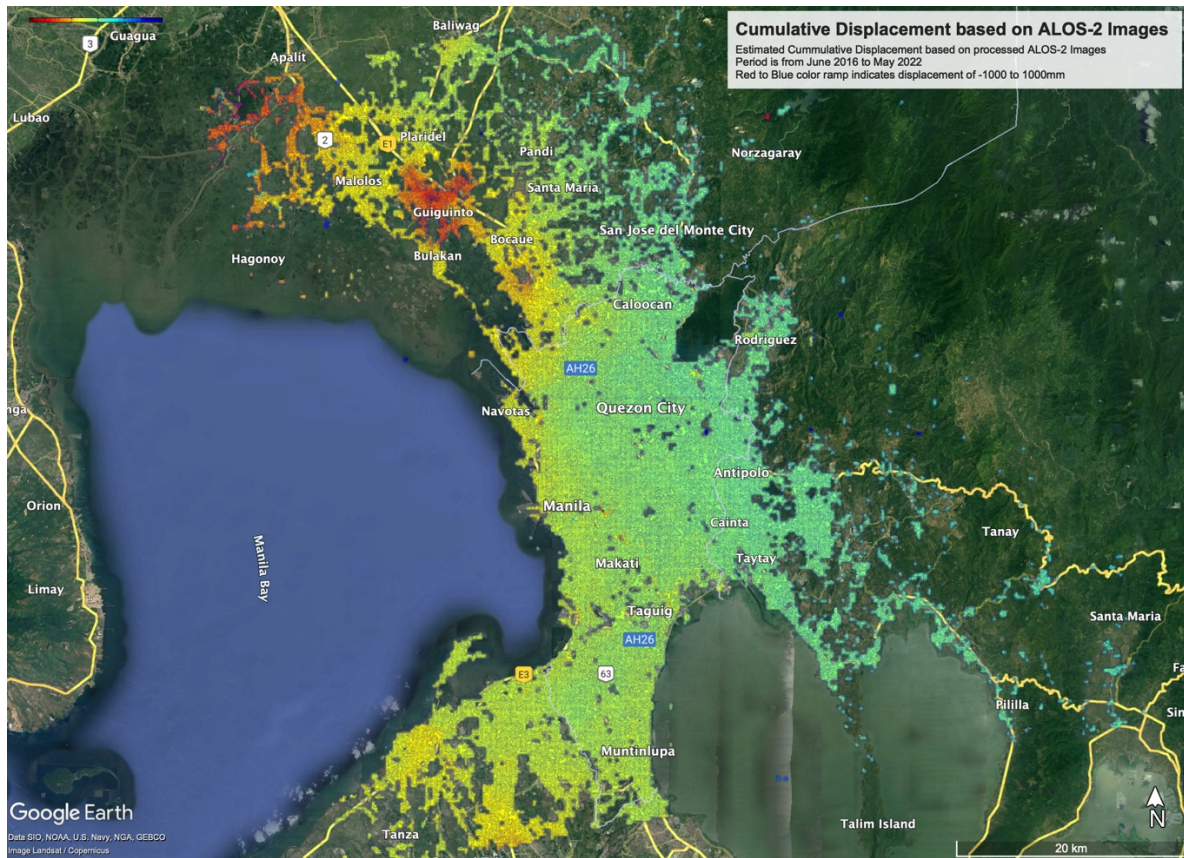


Figure 5. Cumulative displacement map over Metro Manila and nearby provinces generated through PSInSAR analysis of historical ALOS-2 images provided by JAXA.

4. CONCLUSIONS AND RECOMMENDATIONS

This paper contextualizes the efforts of the DOST-ASTI in addressing SDG 13 in the Philippines by adding value to the various earth observation datasets it has access to. The agency, through its SARwAIS team, developed and employed various workflows that use satellite images in mapping the extents of potential flooding, monitoring and inventory of aquaculture structures, and determining the trends of the land subsidence. The generated products are viable options for referencing the implementation of disaster response, rehabilitation of crucial ecosystems, and risk management policies.

It is recommended that other applications intended to cover the impacts of natural disasters, such as, but not limited to, earthquakes, volcanic eruptions, droughts, and forest fires, are explored using NovaSAR-1 SAR and AIS data whenever applicable. While the efforts of the DOST-ASTI can only supplement the indicators of SDG 13 through backing policies with remote sensing data and applications, it is also recommended that the engagement for climate action should be at the national level, to build resilient communities and to mitigate the effects of disasters.

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