Lessonia-1 SAR Project for Improving the Disaster Management in Brazil

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Abstract

The Lessonia-1 Synthetic Aperture Radar (SAR) Project is a significant initiative by the Brazilian Air Force (FAB). It involves the deployment of a constellation of low-orbit satellites, including Carcará I and Carcará II SAR-based microsatellites with dual purposes, addressing both military and civilian needs. The Lessonia-1 satellites provide real-time data for disaster response and management. They monitor natural events such as earthquakes, wildfires, floods, landslides and enhancing surveillance of the Exclusive Economic Zone (EEZ) and border control operations. By capturing SAR images, Lessonia-1 satellites enhance situational awareness during emergencies, enabling timely interventions and resource allocation. SAR technology enables satellites to penetrate cloud cover, providing valuable observations of terrain, even in regions like the Amazon rainforest. Space Operations Center (COPE) has been tasked to acquire imagery from Lessonia-1 SAR to support joint operations to mitigate natural disasters, for instance, flooding and wildfires. This paper aims to explore the characteristics and implementation of the Lessonia-1 SAR Project, operating in X band, with VV polarization imagery in different imaging modes and resolutions to support the wildfire and flooding events in Brazil. The study concluded that Lessonia-1 SAR imagery effectively provide timely and accurate geospatial information for disaster management.

1. INTRODUCTION

1.1 Lessonia-1 Project Overview

The Lessonia-1 Synthetic Aperture Radar (SAR) Project is a part of the Brazilian Strategic Program of Space Systems (PESE) led by the Brazilian Air Force (Ministério da Defesa, 2018). It involves deploying a constellation of low-orbit satellites, including the Carcará-I and Carcará-II SAR-based microsatellites made by ICEYE company. These satellites serve dual purporses, addressing both military and civilian needs. These satellites serve dual purposes, addressing both military and civilian needs. These satellites come as a complete package, capable of performing multiple imaging modes and executing orbital maneuvers. The spacecraft bus (main mechanical structure) has a volume of less than $1m^3$, and the total mass of the spacecraft is approximately 105kg. More details regarding ICEYE sensor specifications can be found in (Ignatenko et al., 2020)

The satellites offer three SAR imaging modes to suit different use cases, Strip (large area, 3m resolution), Spot (precision monitoring, 1m resolution), and Scan (wide-area coverage, 15m resolution). Then, customers can select the most appropriate mode for their specific use case to image areas of interest (AOIs) both regionally and globally. For instance, Scan mode offers wide-area imaging, ideal for extensive maritime regions. This mode also provides situational awareness, allowing you to switch to Spot or Strip mode on a subsequent pass to further investigate a precise target of interest.

By leveraging these advantages, a remote sensing framework can significantly enhance our ability to predict, respond to, and recover from natural disasters, ultimately safeguarding lives and property. This approach ensures better preparedness and resilience, protecting communities and minimizing damage.

1.2 SAR in Support to Disaster Management

SAR is essential in managing natural disasters due to its ability to capture detailed images regardless of weather or lighting conditions (Nhangumbe and Nascetti, 2023). Unlike optical sensors, SAR can see through clouds, rain, and vegetation, making it incredibly useful during emergencies when visibility is often poor (Lahsaini et al., 2024). This capability ensures continuous monitoring and quick assessment of disaster-stricken areas, which is vital for making timely decisions and allocating resources effectively. SAR excels in mapping floods, landslides, earthquakes, and volcanic eruptions, providing high-resolution images that are crucial for damage assessment and recovery planning. Additionally, SAR can detect ground displacement and changes over time, aiding in the prediction and mitigation of future disasters (Bolanio et al., 2022). When combined with other remote sensing technologies and geographic information systems (GIS), SAR enhances the overall efficiency of disaster response and management strategies. By delivering precise and reliable data, SAR significantly reduces the impact of natural disasters on communities and infrastructure, ultimately saving lives and resources.

According to (Shen et al., 2022), floods affect millions of people and cause huge significant property losses annually. The authors emphasize the critical need for precise and near-real-time extraction of flood-inundated areas using SAR images to aid in disaster reduction and emergency response. (Yordanov et al., 2020) underscore the importance of geospatial data infrastructure, highlighting the role of updated remote sensing imagery. (Hrysiewicz et al., 2023) and (Tarpanelli et al., 2022) have shown the effectiveness of SAR images in wildfires and flooding monitoring.

SAR technology plays a crucial role in wildfire management by providing near real-time monitoring and damage assessment

(AlAli and Alabady, 2022). Unlike optical imagery, SAR can penetrate smoke and clouds, offering continuous data regardless of weather condition. This capability allows for accurate tracking of wildfire spread, assessment of affected areas, and timely updates to disaster response teams. SAR’s ability to deliver detailed insights helps in making informed decisions, improving the efficiency of firefighting efforts, and minimizing damage to property and loss of life. Its integration into wildfire management systems is revolutionizing how the society responds to these natural disasters (Barrile et al., 2020).

In this study, Lessonia-1 images are used to support flooding and wildfire affected areas responses in joint operations. Time-series intensity images were analysed using change detection techniques. The results have shown the Lessonia-1 images are feasible in detecting both flooded and burnt areas, providing timely information that can significantly aid disaster response and management efforts.

2. METHODOLOGY

This section outlines the processes within the Lessonia-1 framework. Following an image request, the Image Center analyzes the request and prioritizes them. Then, the Mission Center initiates data acquisition planning at COPE. The satellites are then tasked via the ground segment. Upon completion of the acquisition, the data is downlinked, and the raw dataset is processed into high-quality images, then images are delivered to the final users. Figure 1 outlines the command-and-control cycle of the Lessonia-1.

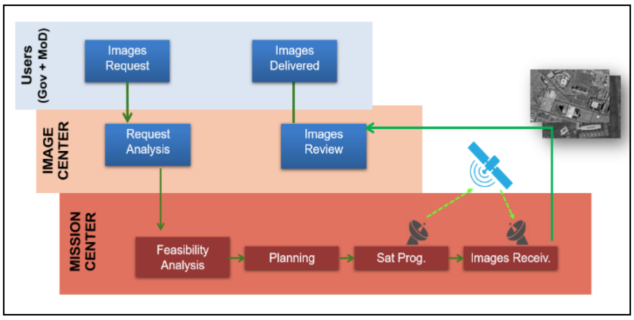


Figure 1. Lessonia-1 Command-Control Cycle

2.1 Mission Planning

After receiving the image acquisition requests with the priorities, the mission planners review them and define a scenario by selecting a period and an AOI. They then choose Lessonia-1 satellites from a list of available sensors, using SaVoir (Planner, 2024) software that combines each satellite’s orbit, sensor field of view geometry, and the AOI’s shape and location to determine the exact times when a satellite can observe the specified area.

The SaVoir imagery planning process encompasses several crucial steps to optimize satellite sensing operations. Figure 2 illustrates sixteen ScanSAR mode images (15m resolution) planned for Rio Grande do Sul (RS) State during the May 2024 floods. These images, captured in both ascending and descending orbits, highlight the comprehensive coverage achieved. The planning ensures precise and timely data acquisition, essential for effective disaster response and management.

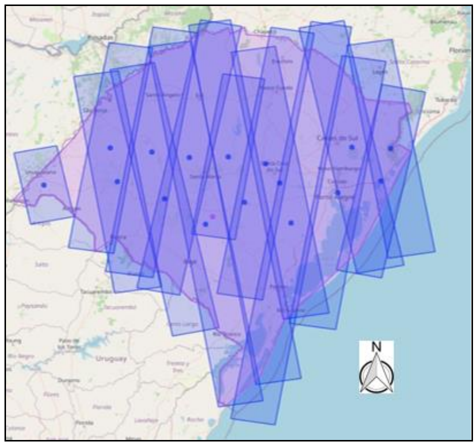


Figure 2. ScanSAR Imagery Planned in RS

The map illustrates the positions of two images from Lessonia-1 in Stripmap mode acquired in 06/24/2024 and 07/23/2024, highlighting their overlapping area in red (Figure 3). Both images were cropped, and subsequently, the AOI (nearby Corumbá city) was further cropped to create the final overlapped images for determining the extent of the burnt area and the monitoring of post-fire effects.

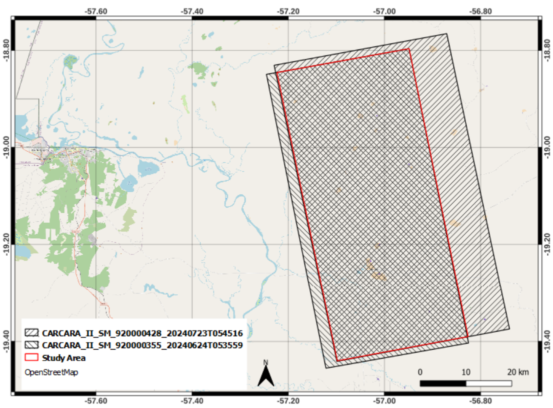


Figure 3. Stripmap Imagery Planned in MS

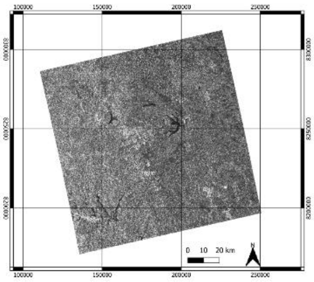
2.2 Datasets Processing

The SAR image processing in the Lessonia-1 Mission Center involves several critical steps to transform raw radar data into usable images. Initially, the SAR system on the satellite emits electromagnetic pulses towards the Earth’s surface and records the backscattered signals. These raw data are transmitted to the Mission Center, where they undergo preprocessing to correct for any distortions caused by satellite’s motion and Earth curvature.

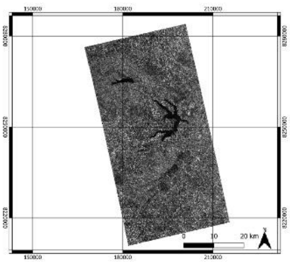
The SAR processor addresses the following effects: range spread loss, elevation antenna pattern, azimuth antenna pattern in spolight mode, variations in azimuth and range bandwidths, and sensor settings variations, including receiver gain, transmit power and duty cycle (Ignatenko et al., 2020).

Finally, the images are analyzed and interpreted for diverse applications, including environmental monitoring, terrain mapping, object detection, and disaster management, ensuring comprehensive and effective utilization of the data.

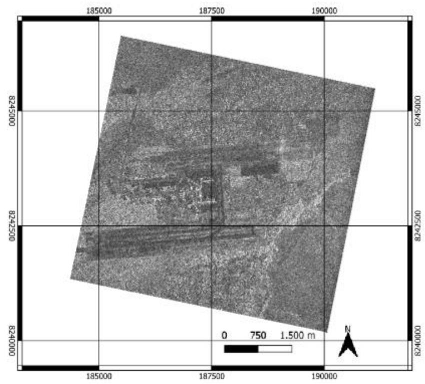
Figure 4 shows the three different imaging modes processed on the Brasília city region: (a) Scan mode with 15m resolution and size of 117km range x 119km azimuth; (b) Strip mode with 3m resolution and size of 34km range x 67km azimuth and (c) Spot mode with 1m resolution and size of 5.4km range x 5.7km azimuth.



(a) ScanSar Image



(b) Stripmap Image



(c) Spot Image

Figure 4. Datasets Processed in the Mission Center

2.3 Datasets Coregistration

Coregistration ensures precise alignment between two or more SAR images taken at different times. Without proper alignment (e.g., vegetation growth and ground deformation) changes in the scene may be misinterpreted or missed. Coregistration process involves these following steps (Zuhlke et al., 2015).

2.3.1 Create Stack: Collocate master and slave images by resampling slave data into the geographical raster of the master image.

2.3.2 Ground Control Points (GCPs) selection: Align master and slave images by matching (GCPs).

2.3.3 Warp: Create a warp function to map pixels from the slave image to the master image.

2.3.4 Input Images: Images must be of the same type (complex or real) and have the same projection system.

3. RESULTS AND DISCUSSIONS

This section discusses the findings from case studies based on SAR images obtained by the Lessonia-1 satellites in Brazil. To explore Lessonia-1 framework, two use cases are presented below.

3.1 Flooding in Rio Grande do Sul State

In May 2024, the State of Rio Grande do Sul experienced devastating floods due to continuous rainfall that began in late April. The Guaiba River, which flows around Porto Alegre, reached unprecedented levels, leading to widespread destruction and impacting over 2 million people. The floods caused extensive damage to infrastructure, including the destruction of bridges, roads, and buildings (Martins-Filho et al., 2024).

Figure 5 shows the image subset from Lessonia-1 SAR acquired in 10/11/2022, prior to the flooding event. In this image, water surfaces such as Gravatai river and lakes appear black. This is due to the low surface roughness relative to the SAR X wavelength in VV polarization, causing specular reflection.

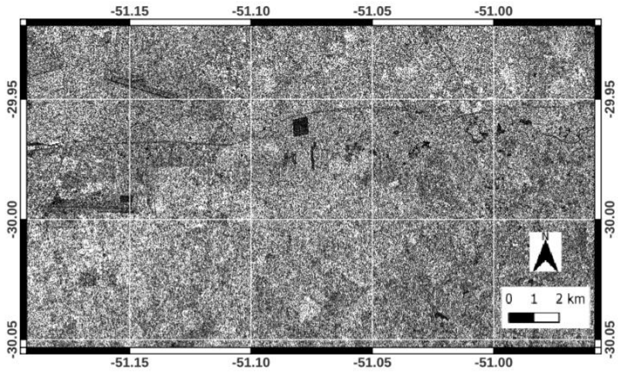


Figure 5. Lessonia-1 SAR Image Subset (pre-flooding)

Figure 6 demonstrates the image subset from Lessonia-1 SAR acquired in 05/18/2024, with the Gravataí River overflowing from left to right. Flooding is also visible at Salgado Filho International Airport near Porto Alegre and in some plantation areas in the right corner of the image. The SAR image uses shades of grey to indicate different land features and water bodies, highlighting the extent of the flooding, that displaced hundreds of thousands of local people and caused extensive damage to infrastructure.

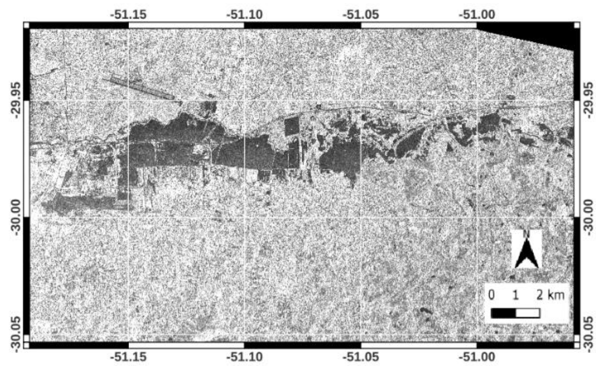


Figure 6. Lessonia-1 SAR Image Subset (post-flooding)

To capture the changes for monitoring the flooding, a false-color composition is performed. It helps in visualizing and interpreting intensity SAR data, making it a powerful tool for environmental monitoring.

Combining the Lessonia-1 SAR images as bands into a single image, this false-color composite highlights differences and changes over time, making it easier to interpret the data.

Figure 7 illustrates the flooded regions with distinct color coding: areas with high inundation backscatter are prominently marked in red, indicating significant flooding. In contrast, regions with lower backscatter returns are depicted in green and blue, highlighting areas with less severe or minimal flooding.

This color differentiation helps in easily identifying the extent and severity of the flood-affected zones.

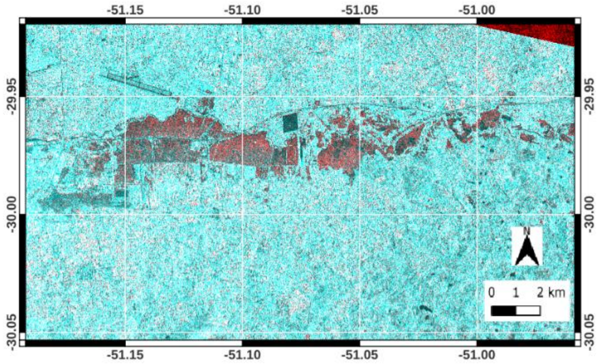


Figure 7. Lessonia-1 False-Color Composition (R:10/11/2022 X_{vv}, G: 05/18/2024 X_{vv} and B: 05/18/2024 X_{vv})

As demonstrated, this method allows for the identification of flooded areas by examining the differences between the pre- and post-flood periods.

3.2 Pantanal Biome Wildfires

The Pantanal biome in Mato Grosso do Sul has been severely affected by fires in 2024. The situation is critical, with fires raging for over three months and destroying approximately 2.5 million hectares, which is about 16% of the entire Pantanal territory in Brazil.

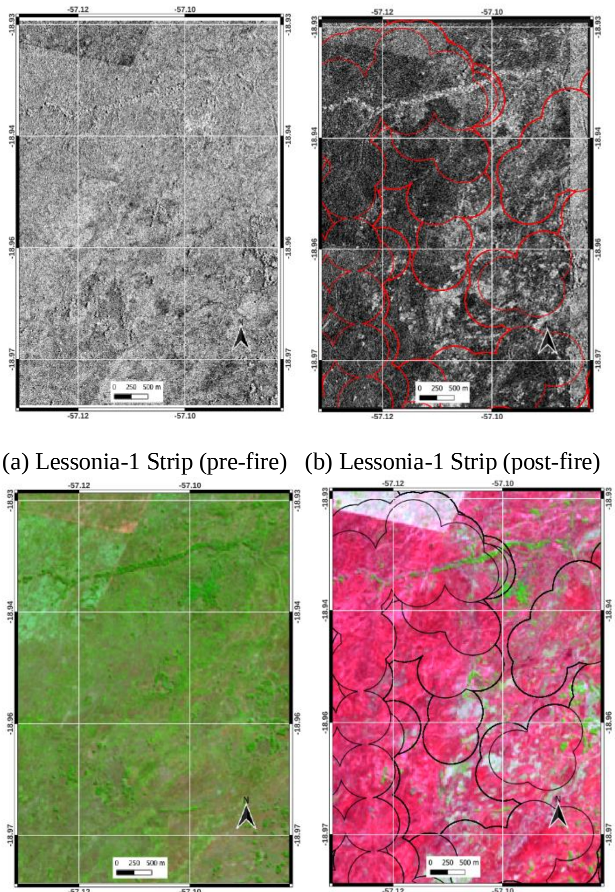
The fires have had a devastating impact on the environment, causing significant loss of biodiversity and threatening the balance of the ecosystem. More details regarding the Pantanal Biome in Brazil can be found in (Silva et al., 2024).
As illustrated in Figure 3, two strip images were obtained to assess the extent of the burned area and monitor post-fire effects in the region near Corumbá city.

Figure 8 shows two subsets of images captured by Lessonia-1: one from June 24, 2024, before the wildfire Figure 8(a), and another from July 23, 2024, after the wildfire Figure 8(b). The post-fire image exhibits significantly lower backscatter compared to the pre-fire image. This reduction in backscatter is primarily due to the loss of vegetation and changes in surface properties caused by the fire. Vegetation typically reflects more radar signals, resulting in higher backscatter. When vegetation is burned, the surface becomes more homogeneous and less reflective, leading to lower backscatter in SAR images.

Two subsets of images captured by Sentinel-2 are used to compare the obtained results in Lessonia-1: one from June 24, 2024 (S2B_MSIL2A_20240624T135709_N0510_R067), before the fire Figure 8(c), and another from July 24, 2024 (S2B_MSIL2A_20240724T135709_N0511_R067), after the wildfire Figure 8(d). To emphasize the burnt vegetation surfaces, a false-color composition was applied using bands B12 (Short-Wave Infrared), B8A (Near-Infrared), and B4 (Red).

This specific combination of bands is chosen because it enhances the contrast between healthy vegetation, which reflects more in the near-infrared and red bands, and burnt areas, which reflect more in the short-wave infrared band. The false-color composition makes it easier to visually distinguish the extent of the fire damage, as burnt areas will appear in distinct colors compared to healthy vegetation. In just one month, the fire devastated the vegetation in the study area of the Pantanal, (Figure 8(c) and Figure 8(d)).

In addition to using Sentinel-2 imagery to assess burnt areas in Lessonia-1 SAR data, the vector layer "mv_indicadores_queimadas," derived from the Painel do Fogo (Antunes et al., 2023), is employed to delineate the boundaries of the burnt regions. This vector layer provides a more precise outline of the affected areas. Figure 8(b) illustrates a red polyline that corresponds with regions of low backscatter in the SAR imagery, indicating burnt areas. Conversely, Figure 8(d) displays a black polyline over a magenta background, highlighting the same burnt regions but in a different visual context.



(a) Lessonia-1 Strip (pre-fire) (b) Lessonia-1 Strip (post-fire)

(c) Sentinel-2 (pre-fire) (d) Sentinel-2 (post-fire)

Figure 8. Lessonia-1 and Sentinel-2 Subset Images in Pantanal region

In the first use case, Lessonia-1 SAR images were pivotal in accurately delineating the extent of flooding. These images effectively highlighted areas with significant water overflow and infrastructure damage. The application of false-color composition was particularly advantageous, as it enhanced the visualization of inundated regions, making it easier to identify and assess the affected areas comprehensively.

For the second use case, SAR images provided a clear and distinct comparison between pre- and post-fire conditions. The observed reduction in backscatter after the fire was indicative of substantial vegetation loss. This change was further corroborated by comparing the SAR data with Sentinel-2

imagery, which validated the extent of the damage and offered a comprehensive view of the affected landscape.
Despite their effectiveness, the use of single polarization in SAR imaging presents certain limitations. Single polarization restricts the ability to capture diverse surface characteristics, potentially reducing the accuracy in differentiating between various types of land cover and changes. This limitation underscores the need for multi-polarization techniques to enhance the detail and accuracy of SAR imagery in diverse environmental monitoring applications.

While Lessonia-1 SAR images have proven to be highly effective in capturing and analyzing environmental changes such as flooding and fire damage, the adoption of multi-polarization techniques could significantly improve the accuracy and comprehensiveness of these assessments.

4. CONCLUSIONS

The Lessonia-1 SAR Project has proven to be a crucial tool in effective disaster management, particularly for natural disasters like flooding and wildfires. By providing timely and accurate geospatial information, the project has significantly enhanced the ability to respond to and manage these emergencies. The use of SAR technology is a key factor in this success. SAR's capability to penetrate cloud cover and deliver detailed images regardless of weather conditions ensures continuous monitoring and rapid assessment during critical situations.

One of the standout achievements of the project is its successful implementation of different SAR imaging modes to monitor and evaluate disaster-affected areas. This demonstrates the versatility and effectiveness of the Lessonia-1 satellites in providing essential data for disaster response. The project has shown that SAR technology can be a game-changer in disaster management, offering precise and reliable information when it is most needed.

Moreover, the project underscores the importance of collaborative efforts in enhancing disaster preparedness and resilience. The cooperation between different entities from MoD has been instrumental in the project's success. This collaboration has not only improved the efficiency of disaster response but also highlighted the value of shared expertise and resources in tackling complex emergencies.

In summary, the Lessonia-1 SAR Project exemplifies how advanced technology and strategic partnerships can transform disaster management. By leveraging SAR's unique capabilities and fostering collaboration among key stakeholders, the project has set a new standard for effective and timely disaster response. This approach not only mitigates the impact of natural disasters but also strengthens overall resilience and preparedness for future emergencies.

For future improvements, it is recommended to integrate Artificial Intelligence and Machine Learning to enhance predictive capabilities and automate data analysis, further improving response times and accuracy in disaster management. Additionally, expanding international collaborations could provide broader data sharing and resource pooling, enhancing global disaster preparedness and resilience.

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