Development and Capabilities of the Arab Satellite 813 for Earth Observation and Environmental Monitoring

Hajer Alabdouli [1], Hasnh Alblooshi [2], Zayed Alkatheeri [3], Mohammed Altamimi [4], Eiman Alshamsi [5], Huijie Han [6], Yinnian Liu [7], Yifei Wang[8], Yonghe Zhang[9]

[1] National Space Science and Technology Centre (NSSTC), Al Ain, UAE – hajeralabdouli@uaeu.ac.ae
[2] National Space Science and Technology Centre (NSSTC), Al Ain, UAE – hasnh_a@uaeu.ac.ae
[3] National Space Science and Technology Centre (NSSTC), Al Ain, UAE – zayed_k@uaeu.ac.ae
[4] National Space Science and Technology Centre (NSSTC), Al Ain, UAE – m.altamimi@uaeu.ac.ae
[5] National Space Science and Technology Centre (NSSTC), Al Ain, UAE – eiman.s@uaeu.ac.ae
[6] Nantong Yangtze Delta Academy of Intelligent Sensing, Nantong, China – hanhj666@163.com
[7] Sate Key Laboratory of Infrared Physics, Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai, China – ynliu@mail.sitp.ac.cn
[8] Innovation Academy for Microsatellites of Chinese Academy of Science, Shanghai, China – wangyifei@microsate.com
[9] Innovation Academy for Microsatellites of Chinese Academy of Science, Shanghai, China – zhangyh@microsate.com

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Abstract

The National Space Science and Technology Centre (NSSTC) in the United Arab Emirates (UAE) is leading the development of the Arab Satellite 813, an Earth observation (EO) platform equipped with hyperspectral imaging (HSI) capabilities. Funded by the UAE Space Agency (UAESA), this satellite aims to provide comprehensive data for environmental assessment and sustainable resource management. Arab Satellite 813 is designed to collect high spatial and spectral resolution data across the blue to Short-Wave-Infrared (SWIR-1) regions of the electromagnetic spectrum. Its primary payload, the HSI, supports applications such as inland water and coastal monitoring, soil characterization, land use mapping, agriculture and vegetation health assessment, and marine pollution monitoring. The satellite also includes a panchromatic (PAN) payload, providing high spatial resolution for detailed observations in specific regions. Additionally, the Atmospheric Polarimeter (AP) payload facilitates polarization data collection, aiding in understanding atmospheric dynamics and correcting HSI data, improving accuracy. The development of Arab Satellite 813 marks a significant advancement in Earth observation, particularly in the Middle East. Through cooperation agreements, data from the satellite can be accessed for research, positioning NSSTC as a key player in hyperspectral imaging. With excellent spectral resolution and high Signal to Noise Ratio (SNR), Arab Satellite 813 will contribute valuable insights into environmental processes and support sustainable resource management and environmental assessment.

1. Introduction

The Arab Satellite 813 is a pioneering hyperspectral Earth observation mission led by the NSSTC. Developed to address pressing environmental and societal challenges, the mission provides hyperspectral data through its advanced payload, developed in collaboration with the Shanghai Institute of Technology and Physics (SITP), the Nantong Academy of Intelligent Sensing (NAIS), and the Shanghai Engineering Centre for Microsatellites (SECM). NSSTC has defined the mission's scientific objectives to deliver valuable insights for environmental monitoring, resource management, and sustainable development. Imaging spectroscopy, which originated in the early 1980s, studies how electromagnetic radiation interacts with materials, supporting both research and commercial applications for examining surface features on Earth and in the atmosphere (Jens Nieke et al. 2023). By analyzing absorption lines of emitted radiation, scientists can determine chemical compositions, as each element has unique absorption characteristics. When ground-test measurements are compared with observed absorption features, the material's constituents can be inferred. Building on this, multispectral and hyperspectral imagers now play a crucial role in capturing detailed spectral information. These advanced instruments are extensively used to study geophysical properties—such as soil composition, nitrogen content in plants, and mineral concentrations, and to monitor atmospheric greenhouse gases like CO_2 and methane. Today's highly sophisticated imaging technologies offer industry-reliable solutions for a wide range of environmental and material analyses. The primary distinction between hyperspectral and multispectral imaging lies in spectral resolution, defined as the ratio of the electromagnetic spectrum range to the number of spectral bands captured by the sensor (Anuja Bhargava et al. 2024). A sensor with high spectral resolution can detect many narrow bands over a small spectral range, while one with low spectral resolution captures fewer bands over a wide spectral range. A key advantage of the Hyperspectral imager Payload is its ability to capture hyperspectral data, consisting of hundreds of narrow spectral bands. Hyperspectral imaging typically operates in a spectral wavelength range between 0.4 – 2.4μm (infrared range), with a spectral resolution within 0.005-0.01μm, enabling detailed material analysis (Nikos Tsoulias et al. 2023). This capability allows scientists to monitor and capture detailed features about vegetation health, soil conditions, methane emissions, and water quality, surpassing traditional Multispectral imaging systems that have lower spectral resolution, typically 0.07-0.4μm.

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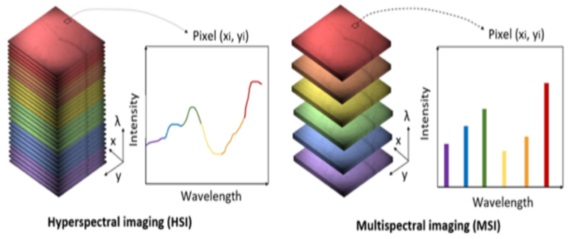

Figure 1. Comparison of hyperspectral imaging (HSI) and multispectral imaging (MSI) techniques.

As illustrated in Figure 1, hyperspectral imaging provides a continuous spectrum that enhances spectral resolution, crucial for detecting subtle environmental changes, while multispectral imaging (MSI) offers lower spectral resolution with faster processing times. This difference underscores the significance of HSI for applications requiring high precision and accuracy. This paper highlights the S813 payloads, focusing on the capabilities of hyperspectral imaging. It begins with an overview of the mission and the UAE's leadership in the space sector, followed by a detailed explanation of the payload's structure and scientific applications. While the mission primarily addresses environmental challenges in the Middle East and North Africa (MENA) region, its data products will also support global research and industrial communities through cooperation agreements, contributing to sustainability and innovation. This mission is a part of the UAE's broader strategic vision for space technology and knowledge transfer, initiated by His Highness Sheikh Mohammed Bin Rashid Al Maktoum. Supported by the UAE Space Agency (UAESA) and UAE University (UAEU), the program emphasizes collaboration through the Arab Space Cooperation Group (ASCG) and provides hands-on training via NSSTC's Assembly, Integration, and Test (AIT) facility, helping to build local expertise in space science. By positioning the UAE as a regional leader in hyperspectral imaging, the Arab Satellite 813 marks a crucial milestone in advancing the nation's capabilities in space technology and environmental monitoring.

2. Satellite 813 Overview

The Arab Satellite 813 is a compact, high-performance Earth observation satellite, designed to capture very high spectral resolution and detailed spatial data. Weighing less than 300 kg, the satellite fits within the small satellite category, providing a cost-effective solution to meet the growing demand for high-precision data. Operating in a Low Earth Orbit (LEO), specifically a Sun-synchronous orbit (SSO) at an altitude of 500-650 km, the satellite ensures consistent, repeated coverage of the same regions at regular intervals, which is vital for long-term monitoring. Although the satellite primarily observes the MENA region, it also provides global coverage to serve broader scientific and industrial needs. The satellite is equipped with an Attitude and Orbit Control System (AOCS) for precise three-axis stabilization, ensuring accurate imaging and data acquisition. NSSTC manages the ground segment, responsible for data reception, processing, and distribution. The satellite mission also integrates training programs through the AIT facility, fostering regional expertise in satellite operations. The Arab Satellite 813 represents a crucial milestone in the UAE's journey toward becoming a leader in space technology. Its advanced hyperspectral imaging payload, cutting-edge control systems, and efficient data infrastructure position NSSTC and the UAE as emerging leaders in the hyperspectral domain.

3. Satellite 813 Payloads

The payload subsystem of Satellite 813 is a highly advanced and integrated system designed to provide high-resolution optical remote sensing capabilities across multiple spectral bands. The subsystem is equipped with three primary instruments: the Hyperspectral Imager, Panchromatic Imager, and Atmospheric Polarimeter, which collectively enable the satellite to capture extensive data for various uses.

The Hyperspectral Imager HSI is the primary instrument aboard the satellite, operating across a broad spectral range from 400 nm to 1700 nm, with average SNR $\geq$ 150 and a spatial resolution better than 20m. Covering both the Visible and Near-Infrared (VNIR) and Short-Wave Infrared (SWIR) bands, the HSI can detect subtle variations in surface materials. It employs a sophisticated optical system, including an off-axis three-mirror telescope and a field-of-view (FOV) separator that channels light into the VNIR and SWIR spectrometers. The spectrometer uses grating spectroscopy, which is essential for minimizing optical aberrations and maximizing data quality, as illustrated in Figure 2, which depicts the configuration of the HSI and its components.

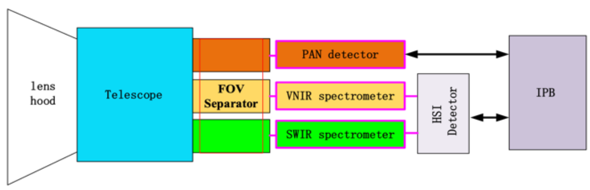

Figure 2. Diagram of the Hyperspectral Imager showing the off-axis three-mirror telescope and other components.

The Panchromatic Imager enhances the spatial resolution of the collected data. Operating in the 450-690 nm range, the PAN provides high-resolution imagery that supports tasks requiring detailed spatial information. This imager works in tandem with the HSI, combining hyperspectral data with high-resolution images to produce enhanced detail crucial for comprehensive mapping and analysis. The AP measures the polarization state of light reflected from the Earth's surface and atmosphere, which is essential for correcting atmospheric interferences in the hyperspectral data. This adjustment ensures the accuracy of measurements related to atmospheric particles and pollutants. By integrating the AP with the HSI, the satellite achieves enhanced data reliability and measurement accuracy, as shown in Figure 3, which illustrates the AP's role in refining hyperspectral data. The payload's thermal and structural stability is ensured by a robust design that includes passive insulation and active temperature regulation components to maintain optimal operating conditions in space. The satellite's lightweight optical frame provides mechanical stability and minimizes thermal distortions that could affect data quality. Additionally, the payload subsystem includes an Image Processing Box (IPB) and an Electronic Control Box (ECB). The IPB is responsible for driving the detectors and managing data processing tasks such as data packaging and compression. The ECB manages power distribution and oversees the payload's control functions, ensuring efficient operation and minimal power consumption. By delivering reliable hyperspectral data, Satellite 813 supports the UAE's strategic goals in space technology and scientific advancement.

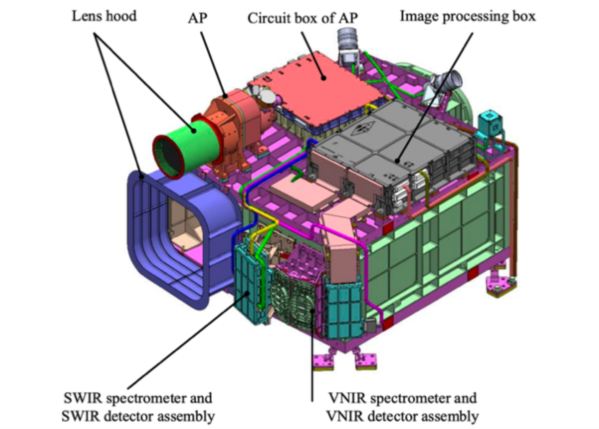

Figure 3. The integration of the HSI and AP components.

4. Satellite 813 Platform

The Arab Satellite 813 platform is comprised of seven key subsystems: the structural subsystem, thermal control subsystem, power and overall circuit subsystem, telemetry, tracking, and command (TT&C) subsystem, AOCS, avionics subsystem, and data transmission subsystem. These subsystems work in unison to ensure the satellite's functionality, stability, and reliability throughout its operational lifespan.

The satellite employs a "vertical stacking" configuration to optimize the integration of subsystems and payloads as shown in Figure 4. The structural subsystem provides support for both the platform and payload, featuring a bottom interface with a four-point attachment system for securing the satellite to the launch vehicle. At the top, an internal primary load-bearing frame offers a stable mechanical interface for the payload.

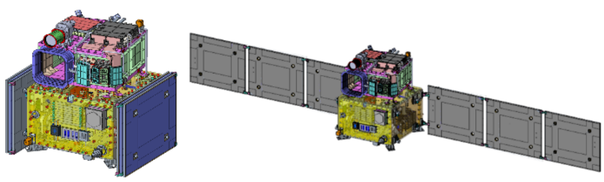

Figure 4. The overall configuration of the Arab Satellite 813 in launch mode (left) and in-orbit mode (right).

Power is supplied by two symmetrical, folding solar arrays that utilize GaInP3/GaAs/Ge triple-junction solar cells, covering a total area of 2.8 square meters. These arrays generate approximately 750 watts of power at the satellite's end of life. Energy storage is managed by a 40 Ah lithium-ion battery pack, while the power subsystem distributes power via a 28V unregulated bus to the satellite subsystems. The thermal design integrates both active heating control and passive thermal dissipation strategies, maintaining the temperature of onboard instruments and equipment within the required operational range.

The Satellite Management Unit (SMU) within the avionics subsystem oversees the operation of most platform equipment. It manages functions such as flight dynamics control, AOCS data processing, telemetry control, and power and thermal management. The X-band data transmission subsystem facilitates the efficient downlink of observation data. It comprises a code & modulator, combiner, and phased-array antenna. This subsystem interfaces with the satellite computer via the CAN bus, receiving control commands and system time to configure operational modes. The TT&C subsystem ensures seamless communication between the satellite and ground stations through S-band channel. This subsystem consists of two S-band and two X-band transceivers, each equipped with transmitters and receivers for signal modulation and demodulation. The TT&C terminal executes direct commands and manages signal encryption and decryption. The AOCS provides the precise pointing and maneuvering capabilities required for Earth observation. It utilizes a combination of sensors, including two star trackers, three gyros, two three-axis magnetometers, and two analog sun sensors, to provide real-time attitude data relative to a reference coordinate system. The avionics subsystem processes this data and generates commands for actuators, which include four reaction wheels, three magnetic torquers, and a propulsion system featuring two 1N hydrazine thrusters.

5. Comparison of hyperspectral missions

Hyperspectral imagers have become increasingly popular in space applications due to their superior spectral resolution compared to multispectral imagers. This enables detailed spectrographic analysis and precise identification of chemical elements on the ground and in the atmosphere. This section compares various hyperspectral missions to the satellite 813 (S813) payload, highlighting its advanced capabilities and innovative features.

Mission	Spectral resolution(nm)	Spatial resolution(m)
S813	5	20
EnMap	6.5	30
GF	10	30
EO-1	9.5	30
Chandrayaan-1	9.8	70
HyspIRI	10	60
PROBA	4.3	17
TacSat-3	5.3	4
MSX	3	770
LEWIS	4.7	30
ENVISAT	1.3	300
HJ-1A	4.3	100
IMS-1	8.6	500
GomX-4B	13.3	50
ISS	11.4	30
German HS	8.5	30
PACE	5	1000
FLEX	0.35	300
CHIME	10	30
PRISMA	9	30
GEO-KOMPSAT-2B	0.8	7000
EOS-3 (GISAT-1)	10.7	200
TEMPO	0.68	4400
Intuition-One	2.87	25
ALTO	20	192

Table 1: Satellite missions containing Hyperspectral imagers.

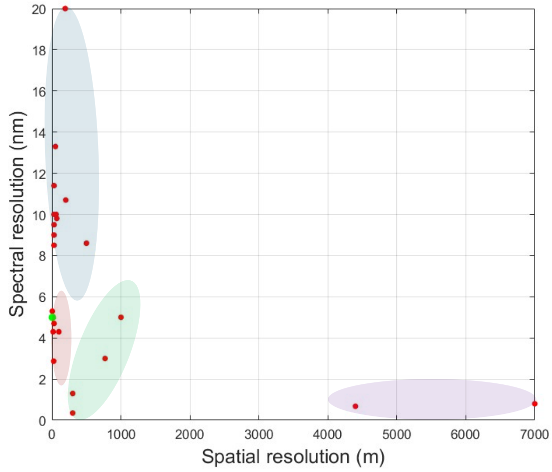

Figure 5. Hyperspectral imagers.

Table 1 presents 20 satellites equipped with hyperspectral payloads, highlighting their diverse properties and applications. Using highest spectral resolution and spatial resolution as key performance metrics, Figure 5 categorizes hyperspectral imagers into four distinct groups:

1. High spectral and spatial resolution (red).
2. High spectral but moderate spatial resolution (green).
3. High spatial but low spectral resolution (blue).
4. High spectral but low spatial resolution (purple).

This classification places the S813 payload among the most advanced hyperspectral imagers, emphasizing its role in the evolution of hyperspectral imaging missions.

Red Group: High Spectral and spatial Resolution
Tac Sat-3's ARTEMIS payload, designed for military applications like battlefield preparation and damage assessment, has a spectral resolution of 5.3 nm and spatial resolution of 4 m (Stanely D et al. 2010). The S813 payload, by contrast, offers a superior spectral resolution of 5 nm, optimized for scientific purposes such as environmental monitoring. While ARTEMIS has slightly better spatial resolution, the S813 excels in achieving a balanced performance tailored for non-military, high-precision applications. The S813 payload outperforms many payloads in the red category, such as LEWIS and Institution-One, in spatial resolution. The S813 outperforms many payloads in the red group, such as Institution-One in spatial resolution. Although Institution-One achieves finer spectral resolution of 2.87 nm, its spatial resolution is 25 m. In contrast, the S813 payload's spatial resolution of 20 m offers superior landmark and topographical accuracy, enabling more detailed and precise observations.

Green Group: High Spectral Resolution
PACE and FLEX are examples of missions within the green category in Figure 5, characterized by high spectral resolutions of 5 nm and 0.35 nm, respectively. FLEX (Fluorescence Explorer) focuses on providing global maps of photosynthetic activity in plants, enabling insights into vegetation health and carbon cycles (WMO OSCAR, 2024). PACE (Plankton, Aerosol, Cloud, and ocean Ecosystem), a NASA mission, is designed to study ocean ecology, including phytoplankton dynamics and their role in Earth's carbon cycle (eoPortal, 2024). Despite their impressive spectral resolutions, the hyperspectral imagers in the green group generally have significantly lower spatial resolutions compared to those in the red group. . In particular, the S813 payload surpasses all green group imagers, with a spatial resolution that is significantly greater. This combination of high spatial and spectral resolution sets the S813 apart, making it a groundbreaking instrument for scientific and environmental studies.

Blue Group: Moderate Spectral and Spatial Resolutions
Payloads in the blue group, such as EnMap, GF-5, EO-1, and PRISMA, typically have spectral resolutions between 6.5–13.3 nm (Qian, 2021), significantly lower than the 5 nm spectral resolution of the S813. While these imagers provide moderate spatial resolution, they lack the fine spectral detail required for advanced scientific applications.

Purple Group: High Spectral and low Spatial Resolutions
Geostationary payloads like GEO-KOMPSAT-2 and TEMPO belong to the purple group, while they have high spectral resolution, but they suffer from extremely low spatial resolutions (>4000 m) due to their orbital altitude. These payloads focus on broad regional monitoring, such as meteorology and air quality, but are not suited for detailed surface-level analysis (eoPortal, 2024) (eoPortal, 2024). The S813 payload, operating in LEO, bridges this gap by combining high spectral and spatial resolution, offering high performance for precise Earth observation.

The data that will be collected by the S813 hyperspectral imager is crucial for a broad range of scientific and environmental applications. This data enables various agencies and research institutions to address critical global challenges, with its high spectral and spatial resolution offering unprecedented insights into environmental monitoring, agricultural practices, and climate studies. Specific applications of this data are explored in detail in the following section.

6. Satellite 813 Scientific Applications

The Arab Satellite 813, equipped with advanced HIS capabilities, has transformative potential for scientific applications relevant to the UAE and global communities. Its hyperspectral data, spanning the 400-1700 nm range, addresses challenges in agriculture, environmental monitoring, urban planning, climate change mitigation, and water resource management, making it versatile for both regional and global use. In agriculture, HSI provides precision farming insights such as crop health, soil composition, and water usage. This allows early detection of plant stress, optimized management of fertilizer and water, and effective disease monitoring. The data supports sustainable farming practices, especially in water-scarce regions like the MENA. By making precise data available, the Arab Satellite 813 enables farmers to make informed decisions that can improve crop yields and sustainability. Figure 6 illustrates the reflectance characteristics of different surfaces, emphasizing how hyperspectral data distinguishes between dry bare soil, green vegetation, and clear water bodies.

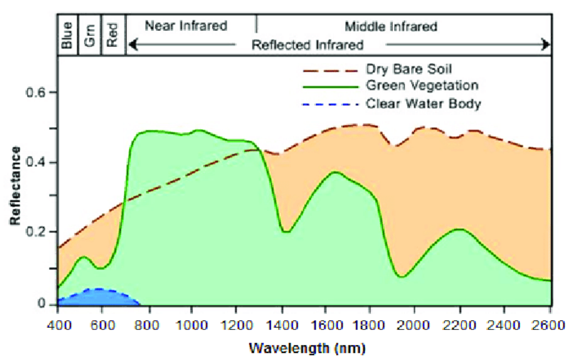

Figure 6. Soil, water, and vegetation curve for spectral response.

In urban planning, the Arab Satellite 813 will play a crucial role. Hyperspectral data from the HSI enables detailed land use classification, infrastructure development tracking, and environmental degradation monitoring in rapidly growing urban centres such as Dubai and Abu Dhabi. By integrating high-resolution imagery from the PAN with hyperspectral data through pan-sharpening techniques, the satellite achieves enhanced spatial resolution, which significantly sharpens classification accuracy. This pan-sharpening process merges the detailed spatial information from the PAN with the spectral richness of the HSI, allowing for fine distinctions between urban materials, infrastructure, and vegetation types. With this combined data, urban planners can more accurately monitor subtle changes in land cover, identify specific materials used in construction, and distinguish between natural and man-made surfaces. This level of detail is invaluable for resource management, enabling planners to optimize land use, mitigate urban heat islands, and ensure sustainable city development. Using data similar to that shown in Figure 7, urban planners gain precise, actionable insights into urban landscape evolution and optimal resource allocation.

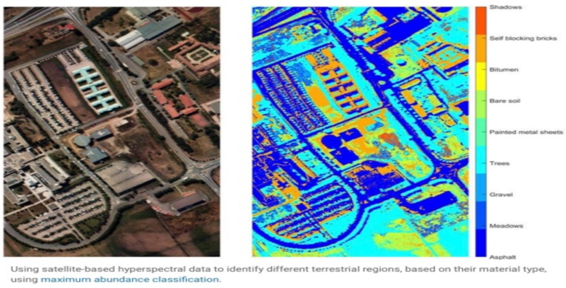

Figure 7. Using satellite-based hyperspectral data for material classification in urban areas.

In water monitoring, HSI breaks through limitations of previous water conservancy remote sensing. The high spatial and spectral resolution of HSI captures the spectral characteristics of various water substances, greatly improving the inversion accuracy of water body elements. Hyperspectral data also enables classification and identification of water elements such as different algae and aquatic grasses, which enhances monitoring and environmental management. While glacier and snow monitoring may not directly apply to the UAE, the satellite's ability to analyze the cryosphere contributes to global climate models by offering insights into how melting glaciers affect sea levels. These changes can have indirect consequences for coastal areas in the MENA region, particularly as rising sea levels impact coastal infrastructure. Atmospheric correction plays a vital role in the post-processing of hyperspectral data, especially with the Arab Satellite 813's integration of the AP payload. The AP measures polarization states, which helps to accurately characterize and compensate for atmospheric interferences such as light scattering and aerosols. This capability is crucial for refining hyperspectral data collected by the HSI, as it ensures that the spectral data remains accurate and reliable even in variable atmospheric conditions. By reducing these interferences, the AP enhances the clarity and precision of hyperspectral imagery, making the data more actionable and suitable for high-precision applications. Figure 8 demonstrates a general example of hyperspectral data before and after atmospheric correction, highlighting the significant improvements in image clarity and reliability provided by the AP. This process is essential for applications across environmental monitoring, resource management, and urban planning, where high data quality is critical for informed decision-making.

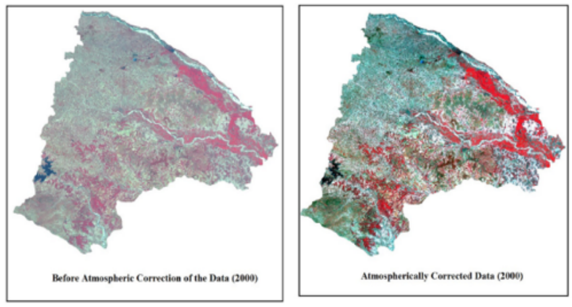

Figure 8. Hyperspectral data before and after atmospheric correction.

The HSI on the Arab Satellite 813 plays an essential role in methane detection. Leveraging the SWIR region, the HSI enables precise identification and monitoring of methane emissions by capturing unique spectral signatures associated with methane. This capability is valuable across scientific communities for applications such as environmental monitoring, climate change research, and industrial leak detection. The integration of high spectral resolution in SWIR allows for the detection of even small methane concentrations, making it a powerful tool for assessing greenhouse gas emissions. Figure 9 illustrates methane detection using HSI, where concentrations of methane are visualized over a landscape, with intensity indicated by a color scale from low (purple) to high (yellow) methane emissions.

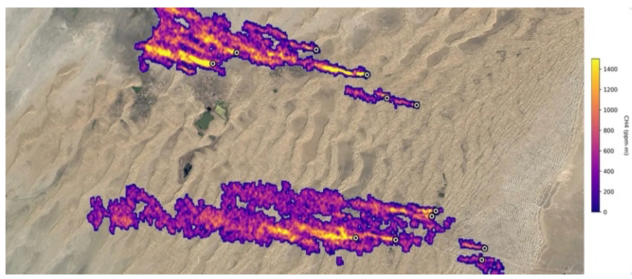

Figure 9. Methane detection.

In inland and coastal water monitoring, hyperspectral imaging within the 400–1700 nm range enables detailed assessment of water quality parameters like turbidity, chlorophyll concentration, and dissolved organic matter. This information is crucial for understanding aquatic ecosystem health and tracking changes over time, supporting authorities in making informed decisions for water quality management. Additionally, HSI effectively detects pollutants and monitors harmful algal blooms by distinguishing between water constituents and identifying spectral signatures linked to contaminants and algal pigments, preventing ecological damage and mitigating public health risks associated with water contamination.

7. Satellite 813 Data Sharing

The Satellite 813 Ground Segment serves as the central management hub for the satellite's overall operations, including ground measurement and control, mission operations, and application management. The scientific data request process starts with users submitting their requests, which are processed through a series of steps, as depicted in Figure 10. First, requests are initiated at the Mission Control Centre, followed by data transmission to the Satellite Control Centre for satellite command execution. The acquired data is then downloaded to the NSSTC Ground Station, where it is processed and made available to users. Through a dedicated user interface, users can search for specific regions of interest, and the data is provided in formats such as GeoTIFF for easy access and further analysis.

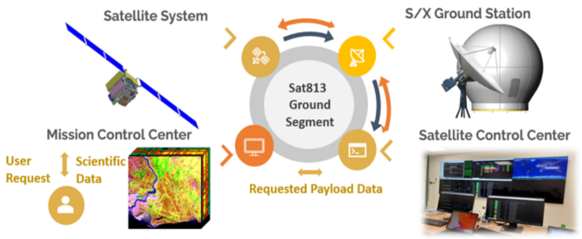

Figure 10. The Satellite 813 Ground Segment

8. Conclusion

The Arab Satellite 813 marks a significant advancement in Earth observation technology, with its hyperspectral imaging capabilities set to provide detailed and high-quality data across various domains. Leveraging instruments like the HSI, which captures fine spectral details in the Short-Wave Infrared (SWIR) region, the satellite will enable precise identification and monitoring of elements such as methane emissions, water quality parameters, vegetation health, and urban materials. This broad range of applications will support informed decision-making in fields as varied as agriculture, urban development, inland waters, coastal monitoring, and land use mapping. The combined impact of the HSI and high-resolution PAN imager promises enhanced data accuracy and fine-scale classification, making the Arab Satellite 813 an invaluable resource for scientific and industrial communities worldwide. The satellite's anticipated contributions are of particular importance to the UAE and the broader MENA region, positioning the Arab Satellite 813 as a key asset in advancing sustainable development, resource management, and environmental conservation. Through cooperation agreements and data-sharing initiatives, the satellite will address global environmental challenges, supporting climate resilience, pollution mitigation, and sustainable practices worldwide. Furthermore, the upcoming deployment of the Arab Satellite 813 underscores the UAE's commitment to becoming a leading force in space technology and environmental monitoring, reinforcing its role as a hub of scientific innovation within the Arab world. With a robust design and advanced imaging capabilities, the satellite will empower diverse end-users with actionable insights, facilitating efforts to address critical environmental and societal challenges. Once launched, the Arab Satellite 813 stands poised to deliver both immediate and long-term benefits, fostering sustainable development and environmental stewardship on a global scale.

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