NarSha: Pioneering The Korean Microsatellite Constellation for Spaceborne Methane Monitoring

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ABSTRACT

Methane (CH_4) is the second most abundant anthropogenic greenhouse gas contributing the global warming. Its global warming potential is estimated to be about 80 times greater than that of carbon dioxide (CO_2) over the last 20 years. To achieve a global net zero in carbon emissions, it is important to monitor and manage point sources of methane emissions worldwide. We introduce the first Korean spaceborne methane monitoring platform development project, termed NarSha. Collaborating with Nara Space Technology, the Climate Laboratory of Seoul National University, and the Korea Astronomy and Space Science Institute, the NarSha project aims to develop and launch the standard microsatellite by 2026. The microsatellite system, named the Korean methane monitoring microsatellite (K3M), is designed to be compatible with the 16U CubeSat standard and is equipped with two optical payloads. The primary payload is a hyperspectral imager operating in the short-wave infrared (SWIR) range, with a spectral resolution finer than 1 nm within the weak methane absorption band (1625-1670 nm) and ground sampling distance (GSD) of 30 meter at an altitude of 500 km. The secondary payload, VIS/NIR camera, is integrated with the hyperspectral imager to identify clouds within its scene. Both payloads have a swath greater than 10 km at 500 km altitude, enabling a local-level monitoring. The agile and precise attitude control system can improve a SNR during the mission. Furthermore, the on-board processing capability and high-speed communication facilitate the delivery of large volumes of raw data essential for the detection and quantification of methane plumes. This proposed system will be operated as LEO constellation to obtain a global methane point source data with high spatial and temporal resolution. This data will significantly contribute to the tracking and quantifying of global methane emissions and establishing a strategy for global warming mitigation. In this study, we introduce the NarSha project and outlines the design of microsatellite systems and the constellation for spaceborne methane monitoring.

INTRODUCTION

In an effort to reduce greenhouse gas emissions and mitigate global warming, 158 countries have endorsed the global methane pledge (GMP), launched at COP26 in 2020. Signatory countries have pledged to cut methane emissions by 30% by 2030, making the global satellite and geospatial sectors crucial for monitoring and enforcing these policies effectively. Since the beginning of industrialization, methane (CH_4) has significantly contributed to 30% of global warming. It has more than 80 times the warming effect of carbon dioxide (CO_2) over the last 20 years [1, 2], yet despite its significant environmental impact, methane emissions are often underreported, with underestimations of 70-80% in some sectors like oil and gas [3].

In 2020, Republic of Korea (hereafter South Korea)'s methane emissions totaled 27 million tons, representing 4.1% of the nation's greenhouse gas emissions. Nearly 97% of these emissions originated from agriculture, waste, and the energy sector, with fugitive emissions from the energy sector alone accounting for 71% of the methane emissions. Due to limited research on downstream emissions, the potential for underreported

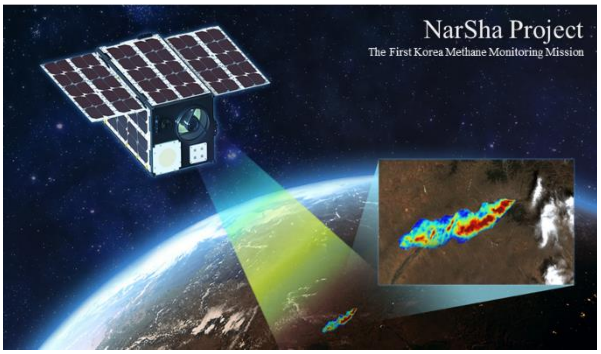


Figure 1: Conceptual illustration of the NarSha project

data is high. With its manufacturing-heavy economy, South Korea has seen one of the highest increases in greenhouse gas emissions over recent decades: In 2021, South Korea was the world's 10th largest economy and ranked 9th in greenhouse gas emissions. South Korea must take actions to reduce methane emissions by 40% from 2018 levels and achieve its ambitious goal of carbon neutrality by 2050 [4]. To initiate the reversal of these trends, it is crucial to enhance our capability to accurately measure the sources and distribution of methane emissions. While global measurements are improving with new data sources and technologies, satellite coverage remains incomplete, with significant data gaps in equatorial regions, offshore operations, and northern oil and gas producing areas [5, 6].

In this paper, we introduce the NarSha, the first Korean spaceborne methane monitoring project. Figure 1 presents the concept of the project. This initiative is a collaboration between Nara Space Technology, Seoul National University's Climate Laboratory, and the Korea Astronomy and Space Science Institute. The NarSha project aims to develop and launch the first microsatellite by 2026. Named the Korean Methane Monitoring Microsatellite (K3M), this system will be equipped with a hyperspectral imager operating in the short-wave infrared (SWIR) range. It will have a spectral resolution finer than 1 nm within the weak methane absorption band (1625-1670 nm) and a ground sampling distance (GSD) better than 30 meters at an altitude of 500 km, covering a swath greater than 10 km.

METHANE MONITORING MISSION

The mission is aimed to detect and quantify methane emissions in multiple point sources using hyperspectral imaging microsatellite system. To enhance a coverage and data production, at least 12 satellites will be operated, achieving daily revisit. The lifetime of each satellite is longer than three years at altitude of 500~600 km.

The mission statement is as follows:

- Develop a hyperspectral microsatellite capable of detecting methane in the atmosphere and operate it for at least three years
- Operate in a satellite constellation and establish a system to produce measurements on methane concentration and emissions in local areas (point sources) and provide data recognized as a reliable measurement method
- Monitor methane emission in local areas (point sources) and provide global data with a focus on South Korea and Asia-Pacific region

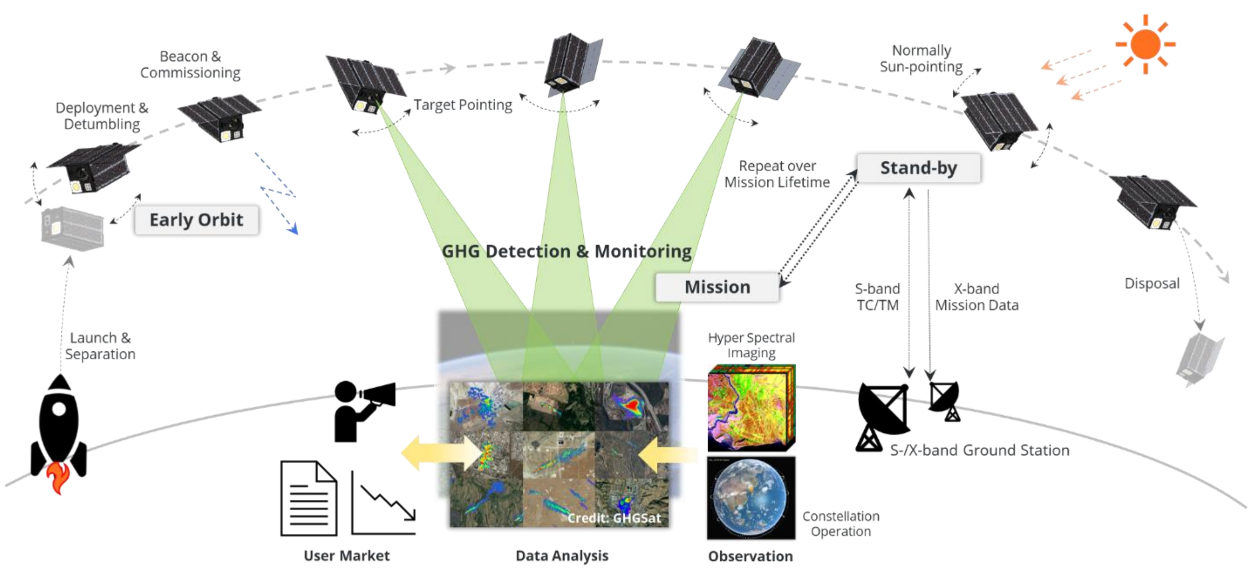


Figure 2: Illustration of the ConOps

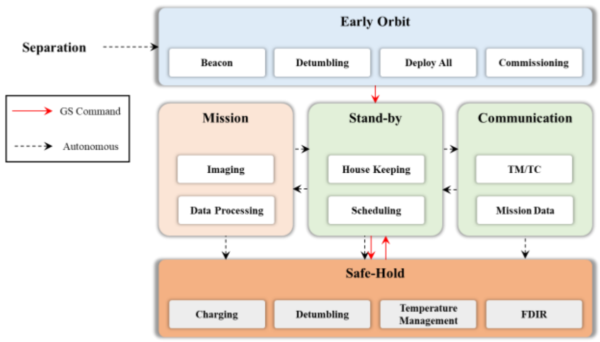


Figure 3: Diagram of the mode change flow

Concept of Operations

Figure 2 shows the concept of operations (ConOps) from launch and separation to disposal. After being separated in orbit, the satellite will deploy solar panels and perform a detumbling. Then, the satellite transmits beacon and conduct a commissioning by ground telecommands. During nominal operations, the satellites will charge the battery by orienting the Sun. With telecommands for imaging, the satellite will point to target for enhancement of the signal-to-noise ratio (SNR). Using the global ground station (GS) services, each satellite will be controlled with S-band communication and the X-band mission data download capacity can be improved with more GS contacts.

The mode change flow is presented in Figure 3. After operations of any modes are completed, the satellite returns to the Stand-by mode automatically. On the Safe-Hold mode, the satellite system recovers its anomalies including a battery under voltage, detumbling, and temperature: the fault detection, isolation and recovery (FDIR) functions are implemented on this mode.

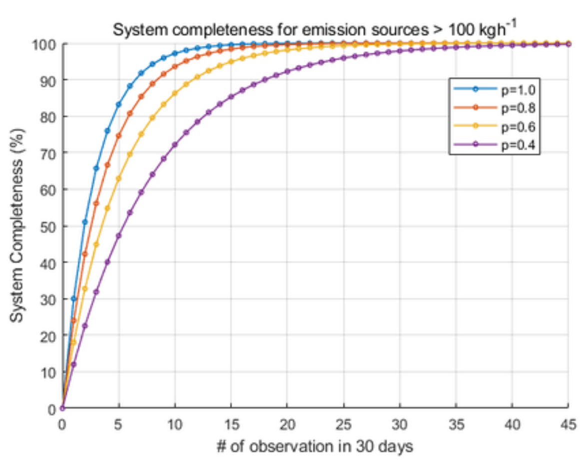


Figure 4: Observation system completeness of the NarSha constellation

Table 1: Parameters on analysis of the observation system completeness of the NarSha constellation

Parameters	Value	Descriptions
Instrument detection threshold fraction (C_D)	1.0	The entire target population to be observed is limited to emission sources with emissions of 100 kg/h or more, assuming that the payload can detect all emission sources at this level.
Spatial coverage fraction (C_S)	1.0	At least once within a 4-week analysis period, it is possible to capture a domain in the field of view (FOV) of the payload, ensuring that the size of the target does not exceed the FOV.
Weather effect (F)	0.3	Considering the weather conditions in South Korea, such as clouds.
Source persistency (P)	0.4-0.8	Referring to the facility operating time ratio according to the emission scale.
Number of observation (N)	every revisit	-

Constellation Design

To provide a service with methane emission data from multiple point sources every 4 weeks, constellation shall be established, covering South Korea and Asia-Pacific region. Assuming that the detection threshold of the methane emissions is higher than 100 kg/h, observation system completeness was analyzed referred to [6]. Table 1 summarize the key parameters used in this analysis.

It is possible to obtain target data from intermittent sources with a 95% probability when observed at least 24 times every 4 weeks as shown in Figure 4. Assuming an average revisit period of approximately 14 days for a single satellite for any given target, the constellation shall be 12 satellites or more for this observation scenario.

MICROSATELITE SYSTEMS DESIGN

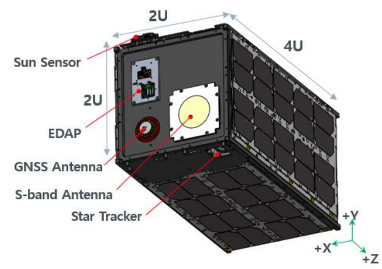
The K3M microsatellite system consists of two optical payloads and 16U CubeSat bus. Table 2 presents the desired performance of the K3M microsatellite system. Each payload covers SWIR and visible & near infrared (VNIR) respectively. The SWIR channel is utilized for detecting methane and carbon dioxide emissions, while the VNIR channel is dedicated to recognizing imaging targets and masking clouds in the scene. With a precise attitude control system, including a star tracker and three reaction wheels, the system achieves pointing accuracy smaller than 0.02 degrees, thus enhancing image quality.

Table 2: Desired performance of the K3M system

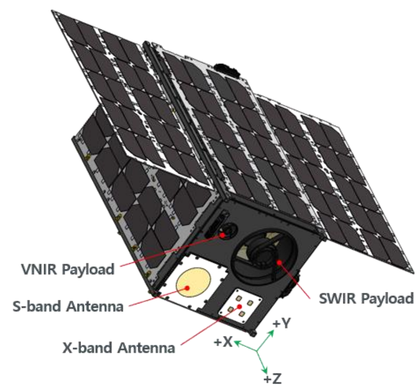
Contents			Performance	Remarks
Mission	Lifetime		>3 years	-
	Orbit		500-600 km	Sun-synchronous
	Spectrum	SWIR	1625-1670 nm	CH_4 & weak CO_2
		VNIR	400-1000 nm	Recognize target & cloud masking
	Detection Threshold		>100 kg/h	Constrained by wind, reflectivity
	Data Availability		L1, L2, & L4	-
	Data Delivery		<4 weeks	Request to delivery, L4
Bus	Size		16U	-
	Pointing Accuracy		<+/−0.02 deg	Target tracking
	Off-Nadir Pointing		<+/−30 deg	-
	Data Downlink		<200 Mbps	X-band
Payload	Size		<12U & 15 kg	-
	Spectral Resolution		<0.3 nm	SWIR FWHM
	SNR		>150	At Albedo 0.2 & SZA 60 deg
	Swath		>10×10 km^2	At 500 km
	GSD		<25 m	At 500 km

Data from multiple missions are downloaded using an X-band transmitter, capable of speeds up to 200 Mbps. For providing highly reliable L2 and L4 data concerning methane emissions concentration and quantification, the spectral resolution or full width at half maximum (FWHM) of the SWIR channel is finer than 0.1 nm, enabling the distinction between ground reflection signals and methane absorption signals. Furthermore, to obtain the data from local area or complex, the swath is wider than 10×10 km^2 at 500 km of altitude.

Figure 5 illustrates the configuration of the K3M microsatellite. The two apertures of the payload and antennas are positioned along the +Z-axis to minimize attitude changes during mission and communication mode operations. The star tracker is tilted to account for Sun and Earth keep-out constraints during maneuvers.



(a) Stowed configuration



(b) Deployed configuration

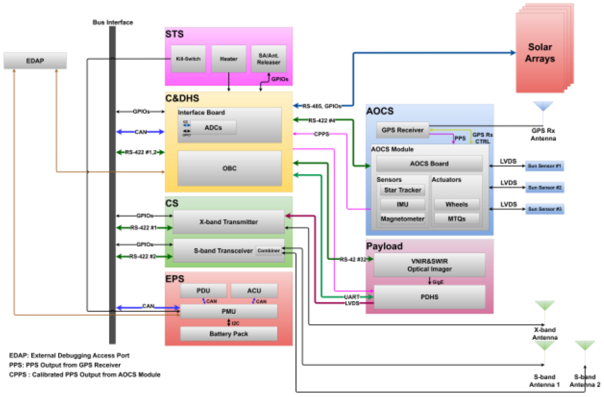
Figure 5: Configurations of the K3M satellites

Systems Architecture

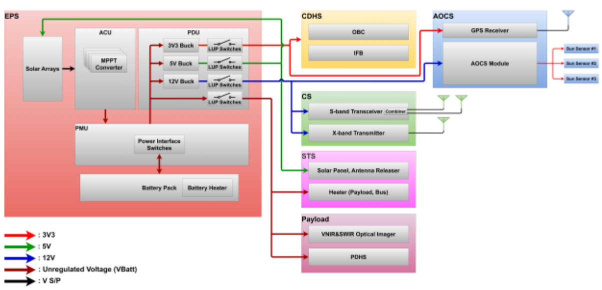
Bus avionics including the integrated attitude control system is fit to 2-by-2 units, allowing 12U for payload. The payload is integrated with SWIR hyperspectral imager, VNIR imager, and data handling system.

Figure 6 illustrates the electrical interface of the K3M microsatellite system. The bus primarily employs CAN bus and RS-422/485 communications. UART and LVDS are utilized for payload control and data transmission, respectively, with LVDS directly connected to the X-band transmitter. Power channels include 3.3 V, 5 V, 12 V, and an unregulated voltage from the battery for each subsystem component, offering protection against over-current with latch-up protection. For payload, only single battery unregulated power is supplied to activate electronics and heaters.

With two single deployable solar panels and 6U-size body-mounted solar panel, the K3M can generate the electrical power over 60 W at end of life (EOL). As summarized in Table 3, all modes secure a positive power margin. As battery capacity at EOL is over 150 Wh, the depth of discharge over mission lifetime guarantees lower than 30%.



(a) Data communication interface



(b) Power distribution interface

Figure 6: Diagrams of the electrical interface

Table 3: Power budget for each scenario

Parameter	**Operation Scenario**			
	Stand-by	Mission	Comm.	Safe
Power Gen. [W]	65.57	45.90	52.46	65.57
Power Draw [W]	25.51	31.59	30.45	11.99
Discharge [Wh]	36.99	45.81	44.16	17.40
Charge [Wh]	73.39	51.37	58.71	73.39
Margin [Wh]	36.39	5.56	14.55	55.99

Payload

The primary payload will be composed of the Ritchey–Chrétien (R-C) type telescope and Fabry–Pérot (F-P) filter or diffraction grid on SWIR sensor to implement hyperspectral imager. The spectral resolution is finer than 1 nm with spectral range of 1625-1670 nm.

The secondary payload will be composed of the R-C type telescope and same sensor with the primary payload. It covers 400-1000 nm for recognizing the imaging target and cloud masking on image.

Finally, each imager payload will be controlled by data handling system, multi-core computing system. The computer will process the images for data compression and on-orbit cloud masking algorithm implementation. Furthermore, thermal control will be established.

16U Bus Platform

Based on the analysis of attitude control performance with star tracker availability, the mounting angle of the star tracker is determined, as illustrated in Figure 7. Simulations accounted for both static and dynamic imbalance of the reaction wheels to mitigate the impact of high-frequency jitters on image quality degradation. It is assumed that the pixel integration ratio should be 70% or higher, requiring an attitude stability better than 0.002 degrees. Figure 8(a) shows the FOV of each sensor.

Given power distribution interface requirements, the power distribution unit controls each power input with an over-current protection. The electrical power subsystem can provide up to 60 W for payload.

The on-board computer (OBC) implements the flight software and control each subsystem component. To save internal space, the OBC mounts the GNSS receiver.

S-band transceiver is used to process telemetry and telecommand, integrated with two antennae for omni-directional communication even in tumbling. High-speed X-band transmitter can download the mission data in single path. Each communication system keeps a link margin more than 3 dB at minimum elevation.

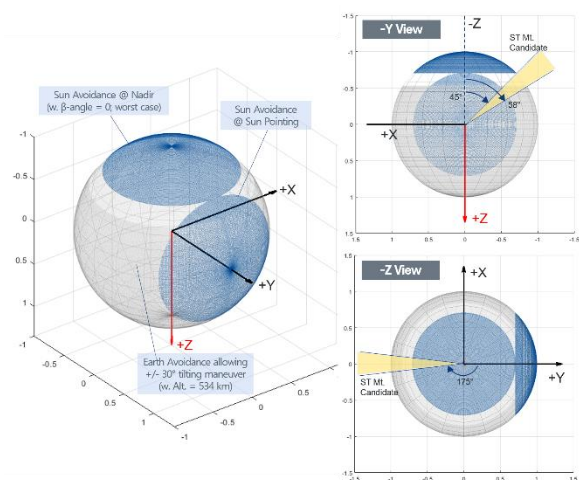
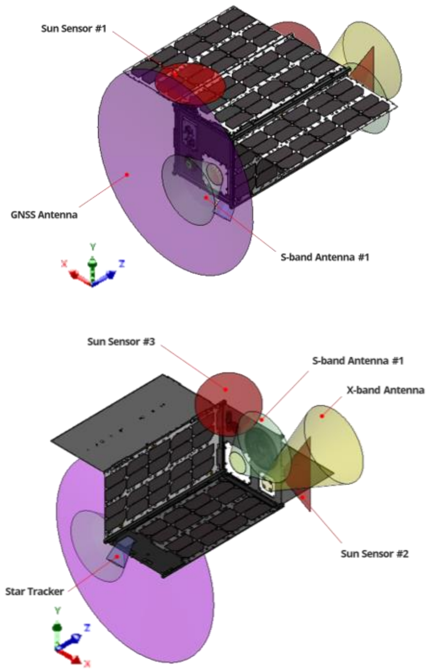
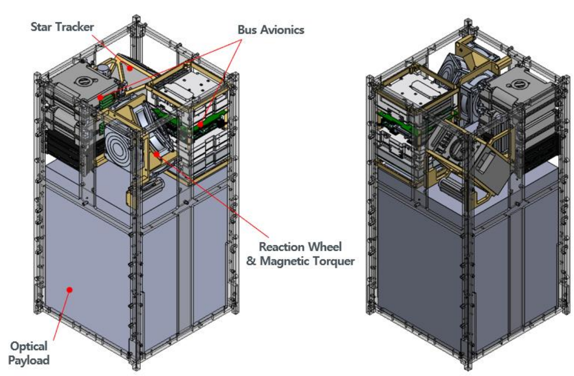


Figure 7: Star tracker availability analysis according to mounting angles



(a) Field of view analysis



(b) Interior configuration

Figure 8: Illustration of the structure design

The structure frame is fit to 16U standard and based on the space qualified design. Considering the payload assembly, the frame is designed using a skeleton configuration with a high degree of freedom. Figure 8(b) illustrates the interior design with payload and bus components.

CONCLUSION

This paper introduces the NarSha methane monitoring microsatellite project, including mission scenarios and system design. The final goal of the project is to detect and quantify the methane emissions in point sources, especially in South Korea and Asia-Pacific region.

To establish a spaceborne methane monitoring system, the optical payload including hyperspectral imagers and 16U CubeSat platform are under development. Furthermore, to improve temporal resolution, 12 or more satellites will be developed as constellation. As the first commercial methane monitoring mission from South Korea, the NarSha project stands out in the Asia-Pacific region, thanks to its unique topographical factors and carbon-oriented industry structure. Furthermore, this constellation will facilitate the accumulation of greenhouse gas emissions data and enhance the accuracy of estimating the effects of global warming from methane.

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