

HUMO 1: A CUBESAT MISSION FOR GLOBAL AIR POLLUTION MONITORING

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Abstract. *This paper presents HUMO 1, a 3U CubeSat mission concept designed for global air pollution monitoring. The satellite aims to measure key atmospheric pollutants, including nitrogen dioxide (NO₂), carbon monoxide (CO), and ozone (O₃), which significantly impact public health and environmental quality.*

Equipped with miniaturized hyperspectral and infrared sensors, HUMO 1 operates in a Sun-synchronous orbit to provide consistent global coverage from low Earth orbit. The mission is expected to generate near real-time pollution maps, identify hotspots, and support data-driven decisions in urban planning, public health, and environmental policy.

As a cost-effective solution, HUMO 1 contributes to advancing global environmental monitoring and promoting cleaner, healthier environments.

Keywords: *Satellite imagery. CubeSat design. Urban planning. Health alerts*

1 Introduction

Air pollution is one of the most critical environmental and public health challenges worldwide. Rapid urbanization, industrial expansion, and increased reliance on fossil fuels have significantly raised the concentration of harmful pollutants such as nitrogen dioxide (NO₂), carbon monoxide (CO), and ozone (O₃). These pollutants contribute to serious health issues, including respiratory and cardiovascular diseases, and disproportionately affect vulnerable populations.

In addition to health impacts, air pollution negatively affects agriculture, reduces visibility, and contributes to climate change. Current monitoring systems, which rely mainly on ground-based stations, provide limited spatial coverage and often lack continuous, real-time data, especially in underserved regions.

To address these limitations, this paper proposes HUMO 1, a 3U CubeSat designed for global air pollution monitoring. Equipped with miniaturized hyperspectral and infrared sensors, the satellite enables high-resolution detection of atmospheric pollutants from low Earth orbit. Operating in a Sun-synchronous orbit, HUMO 1 ensures consistent global coverage and supports the identification and tracking of pollution patterns.

This study presents the mission design, objectives, and expected contributions of HUMO 1 to environmental monitoring and public health.

2 Related Work



CubeSats have emerged as a cost-effective alternative to traditional satellites for Earth observation, particularly in environmental monitoring. NASA's Hyper-Angular Rainbow Polarimeter (HARP) CubeSat, launched in 2019, exemplifies this trend. HARP utilizes a compact polarimeter to measure aerosols and clouds, providing insights into atmospheric composition and air quality. Its successful deployment underscores the viability of CubeSats in atmospheric studies.

Similarly, the TROPICS (Time-Resolved Observations of Precipitation structure and Storm Intensity with a Constellation of SmallSats) mission aims to deploy a constellation of CubeSats equipped with scanning microwave radiometers to monitor tropical cyclones. While primarily focused on weather phenomena, TROPICS demonstrates the potential of CubeSats in atmospheric observation and data collection.

3 Mission Objectives

Satellite-based monitoring is a crucial tool for tracking and understanding global air pollution dynamics.

Primary objective:

The CubeSat's primary mission is the real-time global monitoring and mapping of key air pollutants. The CubeSat will collect and transmit atmospheric data that enables timely analysis of pollutant levels in urban, industrial, and rural areas around the world. It will provide accurate information about the concentration, distribution, and seasonal variation of major pollutants such as nitrogen dioxide (NO₂), carbon monoxide (CO), and ozone (O₃). This data will support early warnings for poor air quality, inform international environmental policies, and contribute to public health and urban planning strategies worldwide.

Secondary goals:

1. For more detailed analysis, the CubeSat will help identify major pollution sources such as industrial zones, traffic-congested areas, and regions relying on fossil fuels for heating and energy. This will support targeted environmental regulations on a global scale.
2. The CubeSat will provide visual and spectral data related to land surface conditions, facilitating studies on how urban expansion and land-use changes affect local and regional air quality worldwide.
3. Another objective is to monitor seasonal and regional trends in pollutant levels, such as wintertime increases in carbon monoxide or summertime ozone peaks due to photochemical activity in different parts of the world.



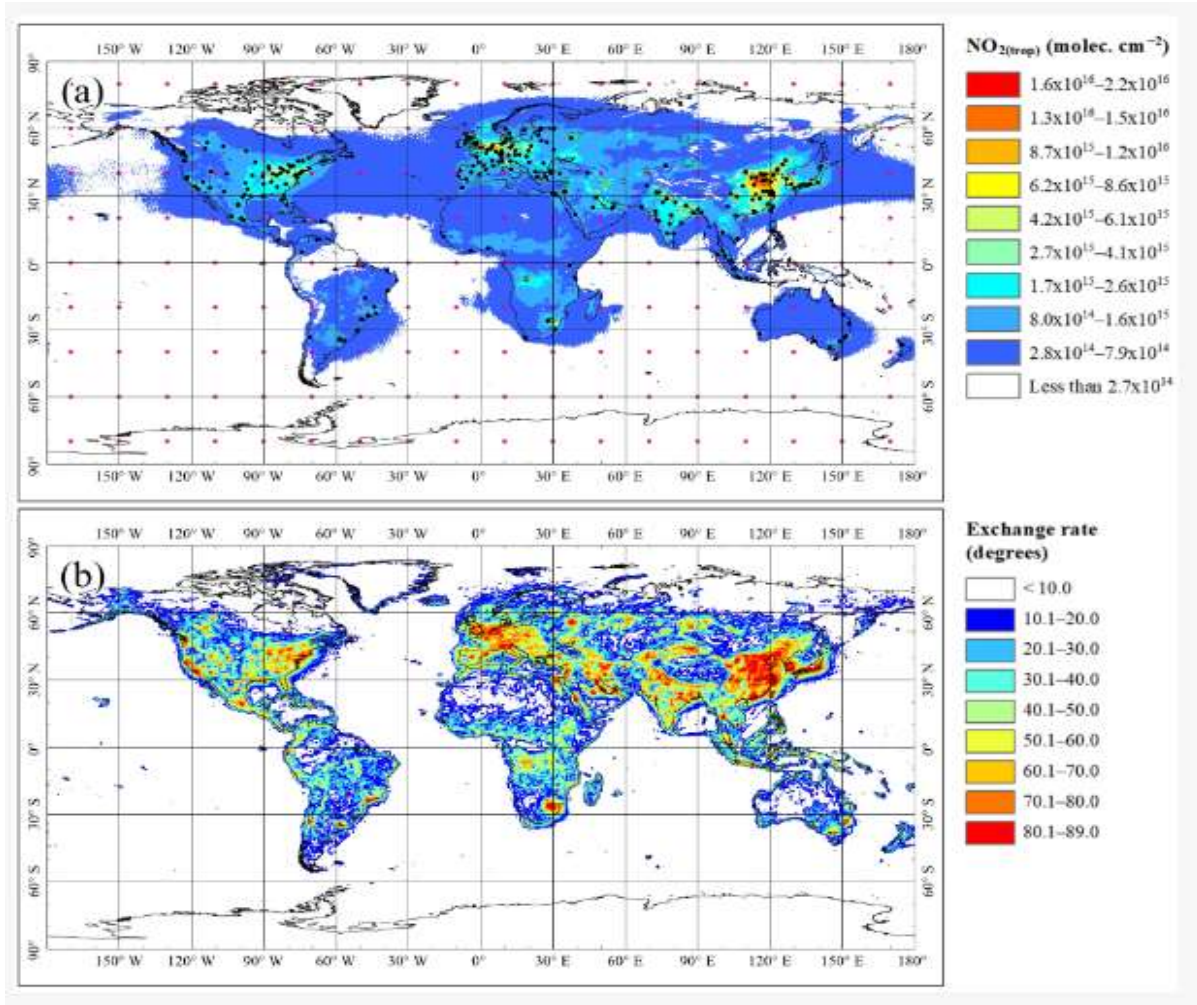


Figure 1. Spatial differences of tropospheric NO₂ (NO₂(trop)) considering (a) the annual average values between 2005 and 2021 and (b) spatial gradients. The 256 most developed cities (black points), complementary 259 sites around the cities (empty points), and systematic sampling network (131 sites, magenta points) with equidistance equal to 20° in latitude and longitude directions.

4 CubeSat System Design (HUMO 1)

This section outlines the system configuration of HUMO 1, a 3U CubeSat (10 × 10 × 34 cm, ~4.5 kg) designed for atmospheric monitoring from low Earth orbit. The design emphasizes compact instrumentation, power efficiency, and reliable communication.

4.1 CubeSat Configuration

Structure and Size:

HUMO 1 follows a standard 3U configuration with an aluminum alloy frame (6061-T6) and passive thermal control using multi-layer insulation (MLI) and radiators.

Payload and External Components:

The satellite carries two main instruments: a hyperspectral sensor for detecting NO₂ and O₃, and an infrared sensor for monitoring CO through thermal emissions. Both are

mounted on the nadir-facing side for continuous Earth observation. Deployable solar panels provide power, while UHF/VHF/S-band antennas enable communication. Attitude sensors, including sun sensors and magnetometers, support orientation control.

Internal Subsystems:

The CubeSat includes an onboard computer (OBC) for data processing and control, a lithium-ion battery for energy storage, and a power distribution unit (PDU) for system regulation. The attitude determination and control system (ADCS), consisting of reaction wheels and magnetorquers, ensures stable Earth-pointing. Data is stored in onboard memory before transmission.

Communication System:

HUMO 1 uses VHF for uplink and UHF or S-band for downlink, achieving data rates up to ~1 Mbps for efficient transmission to ground stations.



Figure 2: 3U CubeSat

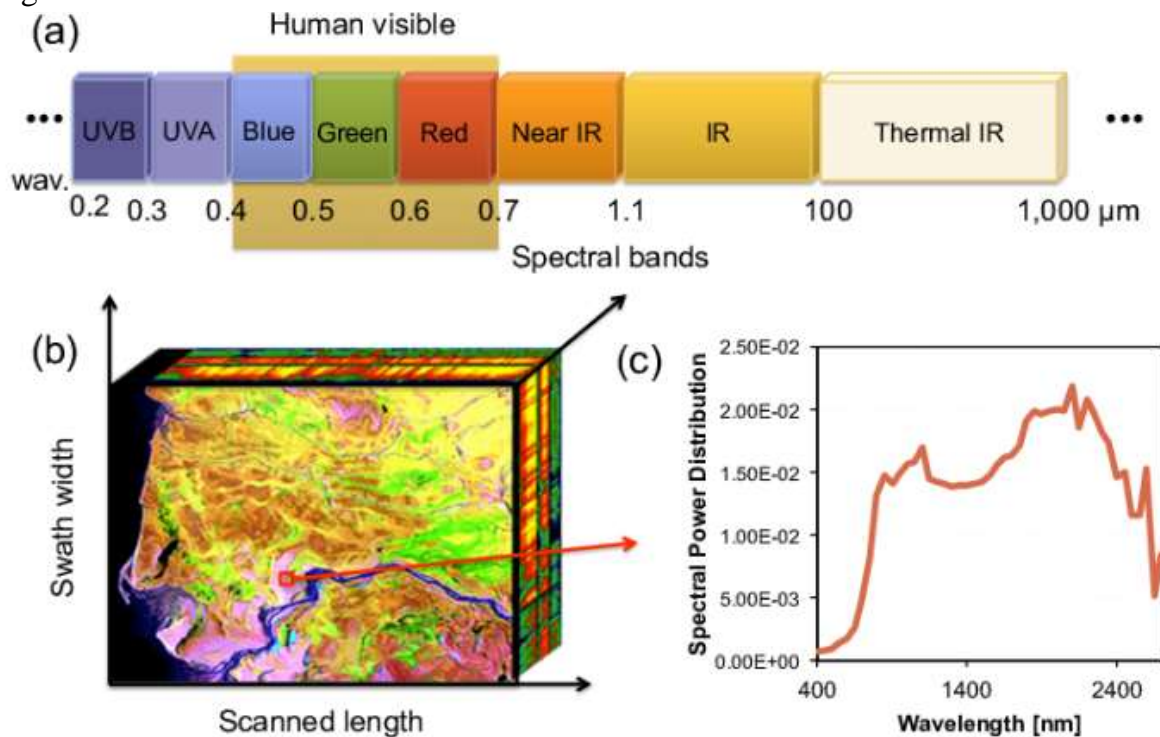


Figure 3. Schematic overview of hyperspectral imaging.

(a) Spectral range across the visible and near-infrared wavelengths, showing how hyperspectral sensors capture data in dozens to hundreds of narrow, contiguous bands.

(b) An example of a hyperspectral image, where each pixel contains detailed spectral information rather than just color intensity.

(c) A sample spectrum extracted from a single pixel, illustrating how hyperspectral imaging enables the identification of specific materials or gases—such as atmospheric pollutants—based on their unique spectral signatures.

5 Orbital Selection

A Sun-synchronous orbit (SSO) in low Earth orbit (LEO) is selected for HUMO 1 due to its ability to provide consistent lighting conditions for Earth observation. Operating at an altitude of 600–800 km, the satellite enables high-resolution global monitoring of key pollutants such as NO₂, CO, and O₃.

With an inclination of approximately 97–98°, the orbit ensures near-global coverage, allowing the CubeSat to systematically observe all regions over time. This makes it well-suited for continuous and long-term environmental monitoring.

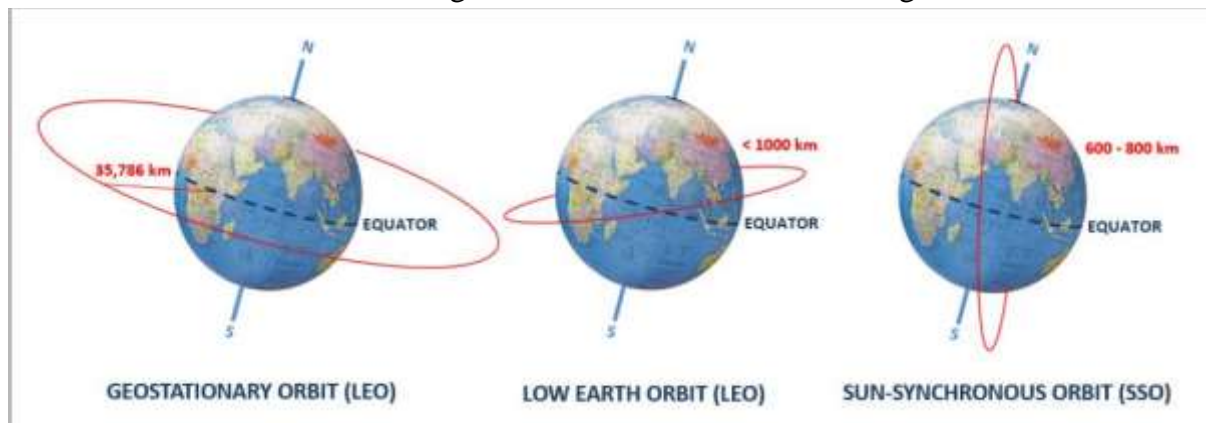


Figure 4: Orbit Types

6 Data Collection and Operations

HUMO 1 collects atmospheric data using hyperspectral and infrared sensors to monitor key pollutants, including NO₂, CO, and O₃. The hyperspectral sensor identifies pollutant concentrations through spectral signatures, while the infrared sensor detects thermal emissions, enabling both day and night observations.

Collected data is processed onboard by the CubeSat’s computer, including calibration, noise reduction, and compression, before being transmitted to ground stations via S-band communication for near real-time analysis.

Operating in a Sun-synchronous orbit at 600–800 km, HUMO 1 ensures consistent global coverage and supports continuous monitoring of air pollution trends.

7 Technical Challenges and Mitigation

Despite thorough mission planning and CubeSat design optimization, HUMO 1 may face several technical challenges during its operation. Below are the key issues anticipated and proposed mitigation strategies:



7.1 Power Management

Challenge:

The hyperspectral and infrared sensors, along with onboard environmental sensors, require a continuous power supply that may exceed the CubeSat's baseline power budget. The hyperspectral imager alone can demand up to 15W during active scanning periods, and the IR sensors add additional power to draw. Moreover, periodic eclipse phases and atmospheric conditions like heavy pollution or dust may reduce solar panel efficiency.

Solutions:

- Operate power-intensive instruments such as the hyperspectral imager in scheduled bursts, focusing on peak sunlight periods and critical monitoring windows.
- Deploy high-efficiency, foldable solar panels to increase total power generation capacity to approximately 40-50W.
- Use high-capacity rechargeable batteries to store excess energy for use during eclipse or low-sunlight conditions.

7.2 Thermal Control

Challenge:

The sensors and electronic components generate heat during operation, while the CubeSat experiences rapid temperature variations in orbit, from extreme cold during eclipses to intense solar heating. These fluctuations can degrade sensor accuracy and component lifespan.

Solutions:

- Employ heat pipes to conduct excess heat from sensors and electronics to external radiators for efficient thermal dissipation.
- Integrate thermostatically controlled heaters to maintain batteries and sensitive electronics within operational temperature ranges (e.g., -20°C to $+50^{\circ}\text{C}$).
- Use durable, atomic oxygen-resistant multi-layer insulation (MLI) blankets to protect against thermal stress and orbital environment wear.

8 Expected Outcomes

The HUMO 1 CubeSat mission aims to deliver valuable outcomes that will benefit scientific research, governmental policy, and educational development on a global scale.

8.1 Scientific Impact

HUMO 1 is expected to provide continuous, high-resolution data on air pollutant concentrations—including nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and particulate matter—across different regions worldwide. This will enhance the scientific understanding of how urbanization, industrial activities, and seasonal variations influence air quality. The mission will support studies on pollutant sources, transport mechanisms, and atmospheric chemistry, contributing to improved global



climate and health models. Furthermore, the data will help identify pollution hotspots and track their evolution over time, enabling more detailed environmental and epidemiological research.

8.2 Governmental Impact

Real-time, space-based monitoring of air pollution will significantly improve environmental oversight and public health management. Governments worldwide will gain access to objective, up-to-date data to inform air quality regulations, urban planning, and industrial emission controls. The HUMO 1 data will enhance early warning systems related to hazardous air quality events, enabling authorities to issue timely health advisories and implement mitigation measures. This is particularly important for protecting vulnerable populations such as children, the elderly, and those with pre-existing respiratory conditions. Additionally, the satellite insights can guide sustainable development policies aimed at reducing pollution and promoting cleaner energy practices.

9 Conclusion

HUMO 1 represents a practical and innovative approach to addressing global air pollution challenges. Rising levels of pollutants such as nitrogen dioxide (NO₂), carbon monoxide (CO), and ozone (O₃) require more effective monitoring systems beyond the limitations of ground-based methods.

This study proposes a 3U CubeSat equipped with hyperspectral and infrared sensors to provide consistent, high-resolution data on air quality from low Earth orbit. The mission enables near real-time pollution mapping, supports early warning systems, and contributes to informed decision-making in environmental policy and public health.

Overall, HUMO 1 highlights the potential of cost-effective CubeSat technology in advancing global environmental monitoring and supporting sustainable development.

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