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Enabling Resilient disaster management and precision agriculture through VLEO Earth observation constellation

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Abstract

Very Low Earth Orbits (VLEO), defined as altitudes below 450 km, are gaining renewed interest in the commercial space sector, particularly for Earth observation (EO) and communication. Operating at these altitudes offers sharper imaging, lower communication latency, and the ability to achieve comparable performance with smaller, more power-efficient payloads. These features make VLEO missions more cost-effective than traditional Low Earth Orbit (LEO) systems. In addition, satellites in VLEO naturally deorbit at end-of-life due to atmospheric drag, reducing the long-term risk of space debris.

These advantages are especially relevant for applications such as disaster management and precision agriculture. Frequent revisit times and rapid imaging can improve situational awareness during floods or wildfires, while high-resolution, multi-sensor data can enhance crop monitoring and resource management to support climate resilience.

This study evaluates the feasibility of VLEO missions through basic system calculations of drag, imaging resolution, and communication latency, combined with case studies in disaster response and agriculture. Representative payloads considered include optical imagers, hyperspectral sensors, thermal infrared, and LiDAR. Emerging technologies such as onboard data processing, drag compensation, and in-orbit servicing are also discussed as enablers for extending mission lifetime and improving responsiveness.

Key challenges include atmospheric drag, short orbital lifetimes, and propulsion constraints. Results suggest that VLEO satellites can provide sharper data, quicker updates, and cost-effective mission designs, while onboard processing reduces dependence on ground stations. With proper enabling technologies, VLEO platforms could support a new generation of agile and sustainable EO missions responsive to both environmental and societal needs.

Keywords: Very Low Earth Orbit, Disaster Management, Edge Computing, Earth Observation, LiDAR, Sustainable Satellites

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Nomenclature

- F_d – Aerodynamic drag force (N)
- ρ – Atmospheric density (kg m^{-3})
- V – Orbital velocity (m s^{-1})
- C_d – Drag coefficient (dimensionless)
- A – Satellite frontal (cross-sectional area (m)
- H – Orbital altitude (m)
- p – Detector pixel pitch (m)
- f – Focal length of the optical system (m)
- GSD – Ground Sample Distance (m/pixel)
- λ – Speed of light in vacuum (~3 × 10^8 m/s)
- NDVI – Normalized Difference Vegetation Index
- SAVI – Soil Adjusted Vegetation Index (dimensions

Acronyms/Abbreviations

- VLEO: Very Low Earth Orbit
- EO: Earth Observation
- LEO: Low Earth Orbit
- LiDAR: Light Detection and Ranging
- ADCS: Attitude Determination and Control System
- PID: Proportional-Integral-Derivative (controller)
- NRT: Near-Real-Time
- GSD: Ground Sample Distance
- FAO: Food and Agriculture Organization
- EMS: Emergency Management Service
- BPHC: Birla Institute of Technology and Science, Hyderabad Campus
- SEDS: Students for Exploration and Development of Space

1. Introduction

Satellites in Low Earth Orbit (LEO) are widely used today for Earth observation and communication. While effective, they often come with high costs, limited imaging resolution, and delays in receiving data. Very Low Earth Orbit (VLEO), defined as altitudes below 450 km, is now being explored as an alternative. Operating at these lower altitudes allows satellites to capture sharper images, communicate with less delay, and use smaller payloads more efficiently. Another advantage is sustainability: satellites in VLEO naturally deorbit at the end of their mission, reducing the risk of space debris.

These benefits make VLEO suitable for applications that demand speed and detail, such as disaster management and precision agriculture. For example, faster revisit times can help provide timely updates during floods or earthquakes, while high-resolution sensing can improve crop monitoring and resource management. At the same time, challenges such as atmospheric drag and short orbital lifetimes need to be addressed. New approaches like onboard data processing (edge computing) and in-orbit servicing are being considered as possible solutions.

This paper looks at the potential of VLEO for sustainability-driven Earth observation, focusing on disaster response and agriculture. It highlights benefits, challenges, and possible solutions in a simple, case-based manner.

The rest of this paper is organized as follows:

- **Section 2** – outlines the approach and basic framework used to study VLEO applications.
- **Section 3** – presents results from two case studies: disaster response and precision agriculture.
- **Section 4** – discusses the findings, identifies the main challenges, and suggests possible solutions.
- **Section 5** – proposes a simple model for future VLEO missions, bringing together lessons learned.
- **Section 6** – concludes with key observations and recommendations.
- **Section 7** – provides supporting figures, charts, and additional details in the appendix.

2. Materials and Methods

2.1 Mission Framework and Orbit Assumptions

This study focuses on Very Low Earth Orbits (VLEO), defined as altitudes below 450 km. At these altitudes, satellites benefit from sharper imaging resolution, shorter communication latency, and natural self-deorbiting due to drag. For this paper, we consider a representative orbit of ~300–350 km, balancing high resolution with manageable station-keeping needs.

2.2 Payload Options

To evaluate the potential of VLEO Earth observation (EO), multiple payload classes were considered:

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- Optical imagers for very high-resolution imaging.
- Hyperspectral sensors for vegetation and material analysis.
- Thermal infrared sensors for heat and stress mapping.
- LiDAR systems for 3D terrain and vegetation structure.

These payloads cover the requirements of both disaster response and precision agriculture use cases. While advanced options such as quantum LiDAR are of interest, they are treated as exploratory payloads and discussed later in the paper.

2.3 Subsystem Considerations

Operating in VLEO requires robust supporting subsystems:

- Attitude Determination and Control System (ADCS): Ensures pointing accuracy for payloads and communications while countering aerodynamic torques.
- Communications and On-Board Processing: Enables timely data delivery by prioritizing critical imagery (e.g., disaster zones) and compressing large datasets.
- Propulsion and Drag Compensation: Provides station-keeping thrust to counter atmospheric drag and extend mission lifetime.

Detailed subsystem modeling (ADCS control loops, data pipelines, LiDAR payload architecture) is included in the Appendix for completeness, while this section focuses on the overall mission framework.

2.4 Application Scenarios

Two application areas were chosen to highlight VLEO's advantages in sustainability-focused missions:

- Disaster Response: Floods, wildfires, and earthquakes require rapid imaging (<1 hour revisit) and quick data delivery for situational awareness.
- Precision Agriculture: Crop monitoring requires high-resolution, multi-spectral sensing at weekly timescales to track vegetation indices (e.g., NDVI) and enable resource-efficient farming.

2.5 Case Study Framework

For each application, we define key performance metrics to compare VLEO and conventional LEO systems:

- Spatial Resolution (Ground Sample Distance, GSD).
- Revisit Frequency (minutes to hours for disasters, days to weeks for agriculture).
- Communication Latency (time from capture to delivery).
- Operational Lifetime (affected by drag and propulsion needs).

3. Theory and Calculations

3.1 Orbital Drag and Lifetime

In Very Low Earth Orbit, atmospheric drag is the dominant disturbance affecting orbital lifetime. The drag force on a satellite is given by:

$$F_d = \frac{1}{2} \rho V^2 C_d A$$

where ρ is atmospheric density, V is orbital velocity, C_d is the drag coefficient, and A is the cross-sectional area.

At 300–350 km altitude, density values from the NRLMSISE-00 model are on the order of 10^{-11}–10^{-12} kg/m^3. Without propulsion, a small satellite at these altitudes may deorbit within weeks to months. This highlights the need for active drag compensation or aerodynamic attitude control to ensure sufficient mission lifetime.

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3.2 Imaging Resolution

The imaging resolution of an optical payload is commonly expressed in terms of Ground Sample Distance (GSD):

$$GSD = \frac{H \cdot p}{f}$$

where H is orbital altitude, p is the detector pixel pitch, and f is the focal length of the optical system.

At 300 km altitude, the same optical payload achieves roughly 2× better GSD than at 600 km. This natural resolution gain is one of the key benefits of VLEO, allowing smaller and lighter payloads to deliver imaging performance comparable to large instruments in higher orbits

3.3 Communication Latency and Link Budget

Communication performance in VLEO benefits from the reduced slant range to Earth. The free-space path loss (FSPL) is given by:

$$L = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

where d is the distance between satellite and ground, and λ is the signal wavelength. At 300 km altitude, FSPL is improved by 3–5 dB compared to 600 km, allowing for lower transmit power or smaller antennas.

The one-way propagation delay is:

$$t = \frac{d}{c}$$

where c is the speed of light. The absolute difference is only milliseconds, but when combined with higher contact frequency in VLEO (more passes per day), the effective data latency is significantly reduced.

3.3 Communications and On-Board Processing

Efficient data delivery and real-time analytics are critical enablers for both disaster response and precision agriculture applications in a VLEO constellation. This section details the communication link characteristics, the architecture of the on-board processing pipeline, and the dynamic priority management that together ensure timely, high-value data products.

3.3.1 Contact Window Characterization in VLEO

A 12-satellite Walker constellation at 300 km altitude completes an orbit every 90 minutes, yielding 8–12 minute ground-station passes and 14–16 daily contacts per fixed ground station. The reduced slant range lowers free-space path loss by 3–5 dB compared to higher LEO, but the limited pass durations constrain total downlink volume to approximately 50–100 Gbit per day per satellite. For midlatitude targets, revisit intervals average 30–40 minutes, while polar regions may see sub-20-minute revisits. To satisfy sub-hour disaster mapping and daily-to-weekly agricultural monitoring, on-board data reduction and intelligent scheduling are mandatory.

3.3.2 Adaptive On-Board Processing Pipeline

The on-board processing pipeline reduces raw sensor data to prioritized, mission-critical products through four key stages. First, radiometric and geometric calibration applies dark-current subtraction and flat-field correction to maintain radiometric consistency within ±2%, while orthorectification using on-board digital elevation models achieves geolocation accuracy of less than 5 m RMSE. Next, cloud and shadow masking employs a tailored U-Net CNN on FPGA hardware, achieving over 95% cloud-pixel detection accuracy in optical bands and discarding more than 40% of unusable area, while shadow detection leverages multispectral thresholds to remove low-radiance regions. In the change and saliency analysis stage, Disaster Mode uses frame differencing and semantic segmentation to isolate flood extents, wildfire perimeters, and storm-damaged zones, flagging regions with over 20% change for priority downlink; Agriculture Mode computes vegetation indices such as NDVI, SAVI, and MCARI per pixel, marking fields with deviations greater than one standard deviation from historical baselines for prescription mapping. Finally, tile prioritization and compression partitions imagery into 256×256 pixel tiles, selecting the top 15% highest-change (disaster) or highest-variance (agriculture) tiles. Optical tiles are compressed using wavelet techniques at a 20:1 ratio with PSNR exceeding 30 dB, while hyperspectral cubes undergo PCA-based dimensional reduction, retaining 95% of spectral variance and reducing data volume by 85%, enabling efficient transmission of the most critical information.

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3.3.3 Priority Queuing and Scheduling

A hierarchical queuing system governs downlink bandwidth allocation in the VLEO constellation. Tier 1, dedicated to emergency data, guarantees a minimum of 2 Mbps during active events, with preemptive access allowing disaster tiles that exceed a 10% areal change threshold to override lower-priority queues. Tier 2 handles agricultural data, permitting up to 4 Mbps aggregate during non-emergency periods, with bulk transfers scheduled during off-peak contacts to meet 24–48 hour delivery timelines for weekly prescriptions. Tier 3, comprising telemetry and housekeeping data, utilizes residual capacity of less than 10% for health monitoring, calibration logs, and software updates. An on-board scheduler forecasts the next three ground passes using TLE propagation corrected for atmospheric drag and allocates transmission windows to maximize high-priority tile delivery. Any tiles unsent due to link outages are automatically re-queued for subsequent passes, ensuring reliable and timely data delivery.

3.4 Quantum LiDAR Integration

Quantum LiDAR harnesses quantum illumination (QI) to extend VLEO sensing capabilities into turbid and occluded environments. This section presents the payload design, performance advantages, integration challenges, and dual-mode operations tailored to disaster and agriculture missions.

The quantum LiDAR payload architecture integrates entangled photon generation, transmit/receive optics, and high-precision detection and timing to enable advanced remote sensing. In the entangled photon generation stage, a PPKTP crystal pumped at 532 nm produces approximately 10^8 photon pairs per second with over 95% fidelity, with the signal photon directed toward the target and the idler retained on-board for coincidence filtering. The transmit/receive optics consist of a 30 cm off-axis paraboloid telescope with wavefront error below 5 μrad, while active path-length stabilization under 100 nm RMS preserves two-photon interference. Detection and timing are performed using SNSPD arrays maintained at 0.8 K with ±10 mK stability, achieving quantum efficiencies exceeding 90% and timing jitter below 20 ps. Coincidences are recorded by time-to-digital converters within a 10 ps window, suppressing background photons and improving the signal-to-noise ratio by 6 dB, thereby ensuring high-fidelity, low-noise measurements for demanding remote sensing applications.

3.4.1 Enhanced Sensing Capabilities

QI's robustness to scattering enables new observation modalities. Subsurface Flood Mapping: the system has demonstrated up to 2 m penetration in 25 NTU water turbidity, accurately mapping urban flood extents beneath murky surfaces, with depth accuracy better than 5 cm achieved through time-of-flight coincidence peaks. Aquaculture & Seagrass Monitoring: depths of 10–30 m can be resolved for seagrass meadows in coastal zones, supporting habitat mapping and aquaculture health assessment, while routine turbidity up to 50 NTU is accommodated with over 75% detection confidence. Smoke-Penetrated Fire Perimeters: coincidence filtering effectively discriminates entangled photon returns from smoke-scattered noise, enabling delineation of fire fronts through aerosol optical depths as high as 3.0.

3.4.2 VLEO-Specific Integration Challenges

Operating quantum payloads in VLEO introduces several integration challenges. Atmospheric decoherence is addressed through adaptive phase-tracking, which compensates for turbulence-induced phase noise and maintains interference visibility above 70%. Thermal control under rapid orbital cycling is managed using a multi-layer insulated enclosure combined with heat pipes and a mini-cryocooler, sustaining SNSPD operation at 0.8 K during 40-minute eclipses and 50-minute sunlight periods. Vibration isolation is achieved with a hybrid passive-active system that dampens disturbances by over 40 dB above 20 Hz, keeping optical alignment within 100 nm RMS even during drag-compensation thruster firings.

3.4.3 Dual-Mode Operational Concept

The quantum LiDAR supports two distinct mission modes. Disaster Mode is triggered by on-board change detection exceeding 20% scene variation, increasing photon pair generation by 50% and narrowing the coincidence window to 5 ps for maximal noise rejection. This mode produces subsurface flood maps and smoke-obscured fire perimeters within 30 minutes, enabling rapid situational awareness. Agriculture Mode, in contrast, is scheduled weekly over agrarian regions and operates at the nominal photon pair rate for two-photon Raman spectroscopy, detecting chlorophyll fluorescence and water content with 1 m spatial resolution and ±2% sensitivity. It generates field health indices and prescription maps within 24 hours, supporting precision farming. By combining VLEO's

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frequent ground contacts with quantum-enhanced detection, the constellation delivers transformative capabilities for both rapid disaster response and precision agricultural monitoring.

3.5 ADCS Subsystem

The ADCS subsystem ensures that the satellite is stable, has the correct orientation for payload pointing, communications, and drag management. Quaternions avoid singularities in Euler angles, so they are used to represent the attitude of the satellite. Unlike the usual LEO orbits, the satellite faces strong aerodynamic torques, high atmospheric density, solar radiation, etc. These disturbances are modeled using the NRLMSISE-00 and HWM14 atmospheric models, Earth's oblateness (J2), and solar radiation pressure.

The aerodynamic force is expressed as follows:

$$F_d = \frac{1}{2}\rho V^2 C_d A$$

To counteract these disturbances, reaction wheels in a four-wheel pyramid configuration provide fine control, distributing body torques via pseudoinverse mapping, while magnetorquers exploit Earth's magnetic field for detumbling and momentum dumping.

A PID-based controller stabilizes the angular rates and minimizes pointing errors. This helps reduce attitude deviation up to within a few degrees in simulation. This hybrid actuation and control strategy demonstrates that robust attitude stabilization in VLEO is feasible, provided disturbance models and active control are carefully integrated

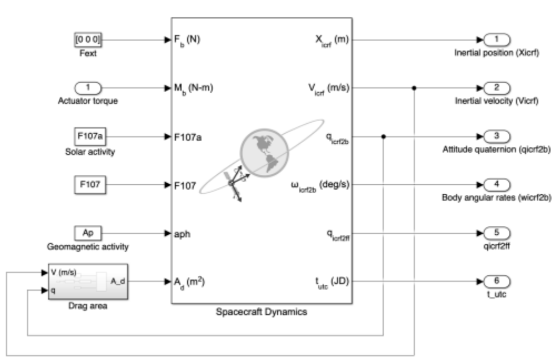

Fig1. Plant model with Earth's oblateness and drag perturbations

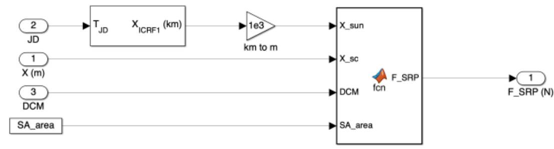

Fig2. Solar Radiation Pressure (SRP block). The output is the exerted force on the spacecraft body

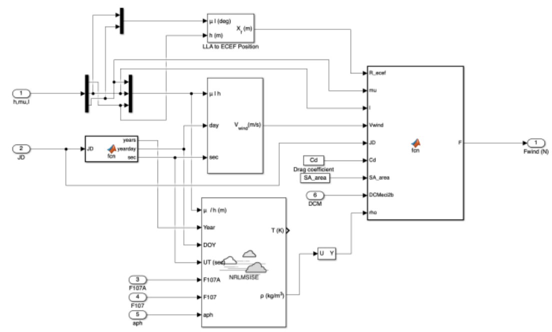

Fig3. Wind drag calculation block. The NRLMSISE-00 model is used to obtain the density, and the Horizontal Wind Model (HWM) 14 is used to obtain the meridional and zonal wind

Drag area block

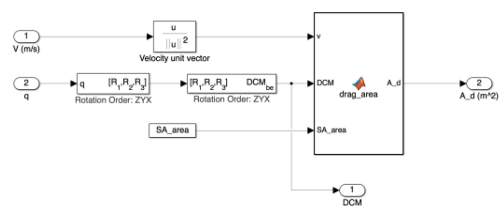

Fig4. Drag area calculations block

4. Comparative Assessment: VLEO vs LEO

VLEO offers a different operational profile compared to higher Low Earth Orbits (LEO, typically 500–1000 km). The key differences are outlined below:

4.1 Imaging Performance

- Being closer to Earth allows VLEO satellites to achieve sharper, more detailed imagery (1–3 m GSD with smaller optics), whereas higher LEO requires larger, more expensive payloads for the same resolution.
- Radar and LiDAR instruments also benefit from improved signal-to-noise ratios at lower altitudes, increasing data quality.

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4.2 Latency and Contact Opportunities

- Shorter orbital periods and closer range reduce communication latency and increase the frequency of ground-station contacts in VLEO, enabling faster data delivery.

- Higher LEO offers longer visibility per pass, but with fewer passes per day and longer delays between revisits.

4.3 Operational Costs

- Launching into VLEO requires less energy than higher LEO, lowering initial launch costs.

- Smaller payloads and reduced system mass further lower production and launch budgets.

4.4 Safety and Environment

- VLEO orbits naturally deorbit within months to years due to drag, reducing long-term debris risks.
- Radiation exposure is also lower at VLEO altitudes compared to higher LEO regions.

4.5 Limitations of VLEO

- Stronger atmospheric drag significantly reduces orbital lifetime without active drag compensation.
- Frequent propulsion maneuvers or in-orbit servicing are required to maintain altitude.
- Ground contact windows are short (5–10 minutes), making onboard processing essential to prioritize data.

4.6 Summary:
VLEO delivers higher imaging quality, faster response, and safer, more sustainable operations compared to higher LEO, but faces challenges with drag and lifetime. For applications such as disaster response and precision agriculture, where speed, resolution, and responsiveness matter more than multi-year endurance, VLEO emerges as the more suitable choice.

5. Demonstrative Case Studies and Findings

- **Note on Case Studies**
  The following case study findings are demonstrative in nature and compiled from multiple operational and technical sources. To maintain readability, inline citations have been avoided here, as they would create unnecessary clutter. Instead, the complete list of references used is provided in the end. These case studies are inferential: no direct numerical simulations were run by the authors. Instead, system-level insights were drawn from published operational data and applied in the VLEO context to demonstrate feasibility and potential mission performance.

5.1 Disaster Response Findings

5.1.1 Operational Baseline

- NASA MODIS/VIIRS flood products → ~3 hours latency from sensing to publication.
- Copernicus EMS Rapid Mapping → first situational reports within a few hours of activation.

5.1.2 VLEO Constellation Advantage

- 10–16 satellites at 260–320 km, spread across 3–4 planes.
- Achieves <60-minute revisit time for declared Areas of Interest (AOIs).
- Onboard prioritization allows "first-look" tiles within 15–60 minutes.
- Full scene products are still within 1–3 hours, matching the current NRT envelope.

5.1.3 Accuracy Improvements

- Copernicus EMS reports 10–20% classification errors in urban/vegetated areas.
- VLEO optical resolution of 0.5–2 m (vs 250–500 m MODIS/VIIRS) reduces false positives.
- Onboard cloud/shadow masking further improves precision/recall.

***5.1.4 Key Benchmark*s**

Key Metric	Current (NASA / Copernicus)	VLEO Constellation
Latency (first look)	~3 hours	15-60 mins
Full product latency	1-3 hrs	1-3 hrs
Revisit Time	Hours to days	<=60mins
Mask accuracy	10-20%	Reduced via

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		higher res + masking
Resolution	250-500 m	1-2 m

5.1.5 Finding:

VLEO satellites make it possible to deliver disaster maps in **under an hour**, giving responders a much earlier view of the situation compared to existing services. Full map products can still be delivered within the usual near-real-time window, but the sharper resolution and onboard filtering mean fewer errors in identifying affected areas, making the information more reliable for emergency response.

5.2 Precision Agriculture Findings

5.2.1 Operational Baseline

- FAO's GIEWS/ASIS programs use NDVI and SAVI indices for **seasonal crop and drought monitoring**.
- Standard requirement: **≥1 reliable observation per field per week** to track vegetation health.
- USGS notes that NDVI accuracy depends on canopy cover, with SAVI performing better in sparse vegetation conditions.

5.2.2 VLEO Constellation Advantage

- 8–12 satellites at 280–350 km altitude ensure ≥90% of fields are observed at least once per week, even under moderate cloud cover.
- Higher resolution (1–3 m optical) allows field-level discrimination, enabling monitoring of smallholder plots that medium-resolution (10–30 m) systems like Sentinel-2 cannot resolve.
- Onboard pre-processing computes vegetation indices (NDVI, SAVI) directly, reducing data volume by up to **70–80%** before downlink.
    - Bulk delivery of prescription maps can be achieved within **24–48 hours** of sensing, aligning with FAO's prescription and advisory timelines.

5.2.3 Accuracy Considerations:

- Literature benchmarks NDVI/SAVI RMSE within 0.02–0.05 when compared to field data.
- VLEO's higher signal-to-noise ratio (lower slant range, better SNR) improves calibration stability across a growing season.
- This supports temporal consistency, a key requirement for crop health monitoring and drought early warning.

5.2.4 Key Benchmarks:

Key Metric	**Current (FAO / USGS Baseline)**	**VLEO Constellation**
Weekly revisit	Sentinel-2: 5–10 days	≥1 obs/week (>90% fields)
Resolution	10–30 m (Sentinel / Landsat)	1–3 m (optical at 300 km)
NDVI/SAVI RMSE	0.02–0.05	Comparable or better (due to SNR)
Delivery timeline	3-7days (regional Advisories)	24–48 hrs (with onboard pre-proc)
Cloud handling	No onboard filtering	Onboard cloud/shadow masking

5.2.5 Finding:

VLEO constellations can deliver **field-level crop monitoring** that is reliable on a weekly basis, with higher resolution images and quicker turnaround for prescription maps. By calculating vegetation indices onboard and revisiting fields more often, they can reduce the time needed to send farm advisories from several days to just 1–2 days, supporting both food security monitoring and precision agriculture.

6. Conclusions

This paper examined the potential of Very Low Earth Orbit (VLEO) satellites for sustainability-focused Earth observation, with a focus on disaster response and precision agriculture. The findings show that VLEO offers clear advantages over higher LEO for these use cases.

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- Sharper imaging & lower latency: At 300–350 km, VLEO enables 1–3 m resolution with smaller optics and shorter data links. Compared to 500–700 km LEO, this yields higher-quality data and quicker access.
- Disaster response: Current NASA and Copernicus services deliver initial flood or fire maps in ~3 hours. A VLEO constellation of 10–16 satellites can achieve sub-hour first-look products while still meeting the 1–3 hour NRT standard, offering a step-change in response speed.
- Precision agriculture: An 8–12 satellite VLEO constellation can provide ≥90% weekly coverage with reliable NDVI/SAVI indices and sub-meter discrimination. This allows actionable crop maps within 24–48 hours, compared to 3–7 days typical at higher LEO.
- Enablers & sustainability: Onboard processing, cloud filtering, and prioritization ensure productive use of short contact windows. Natural orbital decay reduces debris risk, and smaller satellite mass lowers costs, though drag and limited lifetimes remain challenges requiring mitigation.

In conclusion, VLEO is not just an alternative but a superior option for disaster response and agriculture, combining speed, detail, and sustainability. With further work on drag control and constellation scaling, VLEO could define the next generation of Earth observation systems.

Appendix A: Case Study 1: Disaster response (floods and wildfires)[2]

Operational context and sources: Rapid Mapping operations emphasize first situational reports within hours and identify an operational push toward faster activation and delivery; NASA's near-real-time flood services routinely publish global flood layers within about 3 hours using MODIS/VIIRS composites, establishing a practical latency baseline that a VLEO constellation with on-board processing can compress to sub-hour for first looks.

Mission goal: Deliver initial damage assessment maps for responders with sub-hour "first-tiles" while full scenes arrive within the NRT envelope.

Mission parameters to simulate and verify:

Constellation geometry: 10–16 satellites across 3–4 planes at 260–320 km, phased to guarantee <60-minute effective revisit over declared AOIs during activation.

Sensing modes: Panchro/multispectral for change mapping; optional thermal for fires; on-board cloud/shadow masks and change segmentation to prioritize downlink.

Downlink posture: Priority queue grants emergency tiles guaranteed bandwidth during active events, aligned to rapid-mapping practices.

Key performance indicators (KPIs):

Revisit time: Effective revisit ≤ 60 minutes during the activation window compared against Copernicus Rapid Mapping "first report within hours"—demonstrate improvement via constellation sizing and scheduling.

Change detection accuracy: Pixel-level precision/recall of flood/wildfire masks benchmarked against Copernicus/NASA NRT products; includes urban/vegetated area error analysis noted by operational documentation.

Data timeliness: Sensor-to-portal latency histogram; target 15–60 minutes for first-priority tiles; full product availability within the 1–3 hour NRT range used by NASA services.

Feasibility outputs to include:
Contact window accounting and bandwidth utilization to show sub-hour tile delivery is achievable with on-board prioritization.
Sensitivity of revisit and latency to constellation size and ground station count (tied to activation surge conditions).
Why disaster response works in VLEO: Frequent contacts and reduced path loss directly translate to timeliness gains; on-board pre-processing reduces dependence on long contacts and aligns with the NRT operational model already practiced by CEMS and NASA, but with a faster first-look capability that sub-hour revisits make possible.

Appendix B: Case Study: Precision agriculture (seasonal crop monitoring)[2]

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Operational context and sources: FAO programs (GIEWS/ASIS) rely on NDVI‑type indices for seasonal crop and drought monitoring; the literature and USGS documentation establish NDVI/SAVI as standard for vegetation condition assessment and soil‑adjusted performance in sparse canopies, setting robust measurement and cadence expectations for field‑scale operations.

Mission goal: Provide reliable weekly monitoring across large agricultural belts and deliver actionable prescription maps within 24–48 hours of acquisition.

Mission parameters to simulate and verify:

Constellation geometry: 8–12 satellites at 280–350 km to guarantee ≥1 clear observation per field per week, with cloud‑aware tasking and optional SAR‑assisted gap filling as cited in recent agricultural RS practice.

Sensing modes: VNIR multispectral (and hyperspectral where applicable) to calculate NDVI/SAVI; consistent radiometric calibration to ensure temporal comparability per FAO workflows.

Processing: On‑board index pre‑computation with tile prioritization for high‑variance fields; bulk delivery scheduled to meet 24–48 hour prescription timelines.

Key performance indicators (KPIs):

Revisit cadence: Proportion of fields achieving ≥1 valid observation per week (cloud‑screened), matched to FAO's seasonal monitoring expectations.

Vegetation index accuracy: Agreement of NDVI/SAVI against field measurements and FAO/GIEWS reference indicators; emphasize SAVI's robustness in low vegetation cover per USGS guidance.

Prescription map generation: End‑to‑end timeline from sensing to delivery within 24–48 hours; quantify bandwidth saved by on‑board pre‑computation and prioritized downlink.

Feasibility outputs to include:

Weekly hit‑rate analysis under regional cloud statistics; constellation sizing required to reach ≥90% weekly coverage across a 200×200 km breadbasket.

Index stability over season demonstrates calibration integrity aligned to FAO program expectations for early warning and input optimization.

Why agriculture works in VLEO: Lower altitude enhances native resolution and SNR, enabling meter to sub‑meter field discrimination with smaller optics, while constellation scaling secures consistent weekly cadence required by FAO‑style seasonal monitoring and operational prescription timelines.

Optional third case study (if a second disaster type or mixed hydrology–agriculture region is desired)
NASA NRT HYDRAFloods and service endpoints provide reproducible flood layers and workflows that can be paired with agricultural NDVI time‑series over flood‑prone farmlands to demonstrate dual‑benefit monitoring (rapid inundation assessment followed by seasonal recovery tracking and prescription support).

This combined case allows testing a single AOI under both crisis and routine modes, exercising priority queuing and switching between emergency and agricultural pipelines.

How to use these case studies to build the ideal mission plan and feasibility checks
Constellation design: Size planes and satellites to meet sub‑hour emergency revisit and weekly agricultural cadence simultaneously over selected AOIs; verify via access analyses.

Link/processing budget: Use NASA NRT timelines and CEMS activation expectations as external baselines; demonstrate tile‑first delivery within 15–60 minutes and full products within the NRT window with on‑board reductions.

Validation: Benchmark flood/wildfire masks and NDVI/SAVI outputs against CEMS/NASA layers and FAO/USGS references, reporting precision/recall and index RMSE; document data sources and API endpoints for reproducibility.

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These cases are purpose-built to let the VLEO architecture prove its value with measurable KPIs aligned to established operational programs and public datasets, ensuring that results can be independently verified and compared to today's best practice.

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