Ground-based TD-LIDAR for methane EO Cal/Val: insights from the BioMethane Tracer Project

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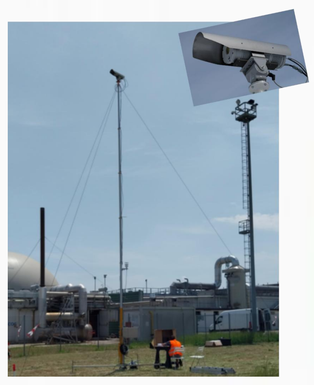
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Abstract

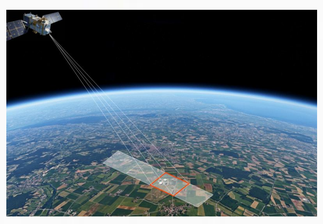
The increase **in methane emissions** into the atmosphere contributes significantly to climate change. The expanded deployment of renewable energy technologies, specifically **anaerobic digestion** for biogas production and its subsequent upgrading into **biomethane**, requires stricter control over potential leaks in order to prevent uncontrolled atmospheric emissions. The growing capability of high-resolution **Earth Observation (EO)** systems to detect, localize, and quantify methane point sources creates a corresponding need for independent **ground-based observations** suitable for data validation and inter-comparison. We demonstrate here an opportunity to deploy the spatially scanning **TD-LiDAR**, a remote-sensing device capable of performing **continuous monitoring (24/7)** of industrial facilities for the **detection and quantification** of uncontrolled biogas/biomethane/methane leaks, to support and complement **Leak Detection and Repair (LDAR) programmes.**

The «BIOMETHANE TRACER» Project

The BioMethane Tracer project, co-funded by the Emilia-Romagna Region (PR-FESR 2021–2027 Programme), developed an **integrated, multi-scale approach** to **characterize methane emissions** in complex industrial environments, demonstrated through **field campaigns** at operating **anaerobic digestion facilities**. The methodology combines facility-level and source-level assessments, integrating **continuous, spatially resolved TD-LiDAR observations** with complementary **in-situ measurements** and source-specific emission estimation methods. For methane EO Cal/Val, this framework offers a basis for establishing the facility's emission state around **satellite overpasses**, helping to distinguish discrepancies attributable to the measurement methods from those caused by actual changes in emission sources.

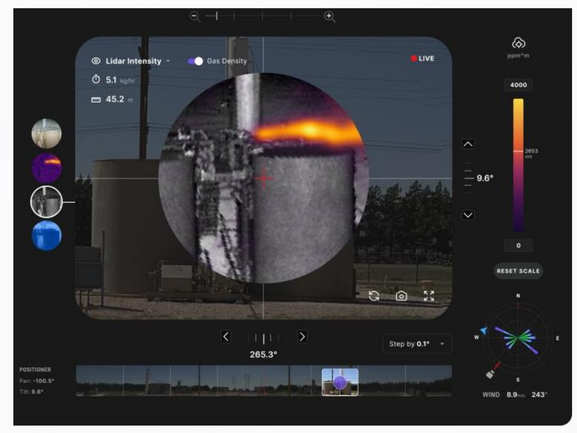


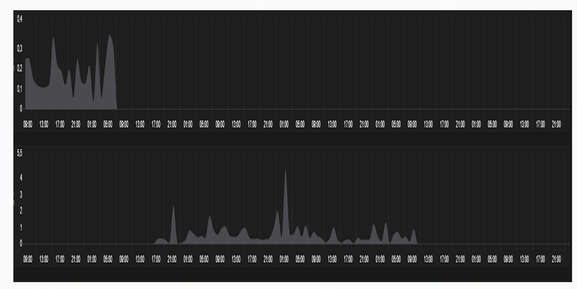




TD-LiDAR description

The ground-based **Tunable Diode LiDAR (TD-LiDAR)** system combines **Laser Absorption Spectroscopy (TDLAS), Differential Absorption LiDAR (DIAL)** and **Time-Correlated Single-Photon Counting (TCSPC).** The instrument simultaneously measures **path-integrated methane concentration** (ppm·m) and distance, enabling spatially resolved imaging and **3D localization** of methane plumes. Mounted on a ~10 m mast equipped with a motorized pan–tilt platform, the system performs **automated 24/7 monitoring** of predefined plant areas. Combining methane plume measurements with local wind observations enables **emission-rate estimation (kg_{CH_4} h^{-1})** and characterization of temporal emission patterns.





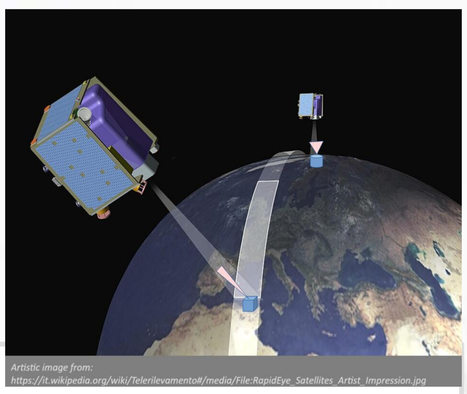
EO data validation procedure considers:

- **Measurement geometry** from the space and from the ground in order to find the best matching.
- Reducing **the time difference** between satellite overpass and ground-based measurements.
- Selection of appropriate **satellite ground pixels** close to **nadir** in order to reduce the non-plant environmental noise.

TD-LiDAR — Technical specifications	
Laser wavelength	Eye-safe IR (1651 nm)
Laser output power	10 mW
Power consumption	21 W
Acquisition time	~ 180 s per frame
Detection range	[10 – 200] m
Accuracy	< ±10% (ppm · m)
Leak Rate Accuracy	Within a factor of 2
Detection limit (90% PoD)	0.2–2.0 kg_{CH_4}/h (<100 m); 0.4–4.0 kg_{CH_4}/h (<200 m)

Satellite data validation

Earth's climate studies cannot achieve representative scientific data without paying particular attention to **the characterization of the scientific payload**. Although pre-flight procedures simulate space conditions and the geometry of planned in-orbit measurements, many factors cannot be reproduced in a laboratory setting. Instrumentation **for post-launch validation procedures**, such as **ground-based instruments**, aircrafts, ships, balloons or probes are therefore applied to overcome such limitations.



State of the art

GHGSat: Targeted ~25 m × 25 m, monitoring individual industrial facilities and assets.
PRISMA / Carbon Mapper: Targeted 30 m × 30 m, identifying super-emitters and point-source leaks.
MethaneSAT: Targeted 100 m × 400 m, identifying diffuse emissions and intermediate-scale sources.
TROPOMI: 5.5 km × 3.5 km - Daily global mapping and atmospheric macro-trends.

Conclusions

- TD-LiDAR represents an opportunity to provide **continuous, real-time and high-quality data**.
- TD-LiDAR provides 3D **localization and quantification** of methane leaks.
- **High sensitivity**: 0.05 g/s at 100 m, wind <1 m/s; 1.1 g/s at 200 m, wind <10 m/s.
- TD-LiDAR represents a valuable **ground-based instrument** for post-launch validation of satellite measurements.

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