

Balloon configurations and Volcanosonde development



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Scope of the Project:

Designing, building, testing and flying a suite of sensor system on a tethered aerostat. The intended system aims to be an in-situ, low cost, modular, long-permanence way to collect in situ measurements from volcanic plumes, in particular gas concentration and ash.

Why monitoring plumes?

- Hazard for health
- Impact on aviation
- Impact on climate / aerosols
- Support to volcanological interpretation

Remote Sensing State of the Art:

- UV / VIS / TIR cameras
- Lidar
- Satellite observations

**Mostly
Indirect!**

Main Limitations

What needs to be measured?

- Gas composition: CO₂, SO₂, H₂S / HCl
- Particulate load: PM / ash content
- Plume structure: altitude, thickness, variability
- Time evolution: transient vs persistent features

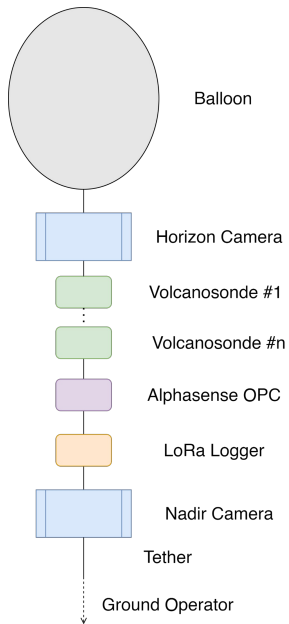
Assumptions are to be made:

- Particle size distribution and gas composition
- Gas concentration
- CO₂ especially difficult due to strong atmospheric background
- Short-term / small-scale plume variability can be hard to constrain

Need for more in-situ measurements!

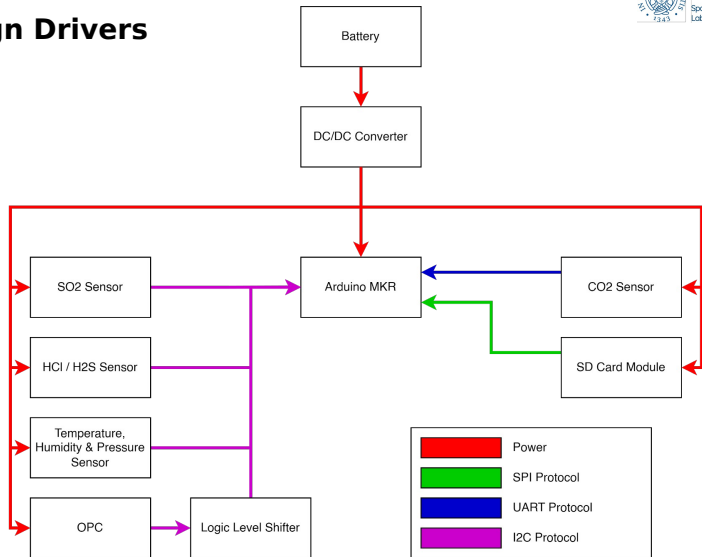
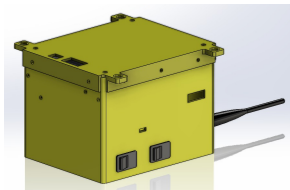
Platform	Drone / UAS	Free-flying balloon	Tethered balloon
Strength	Maneuverability	Vertical profiling	Persistent controlled sampling
Limitation	Limited endurance / plume disturbance	Limited control / recovery risk	Wind and lift constraints

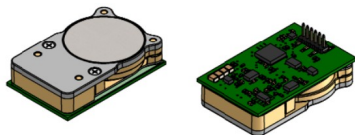
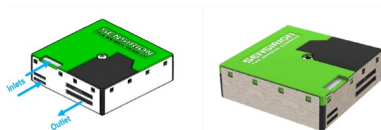
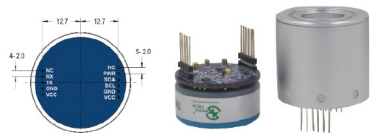




Volcanosonde Design Drivers

- Low mass / low volume
- Low cost
- On board power supply
- Real-time telemetry
- Modular sensor suite

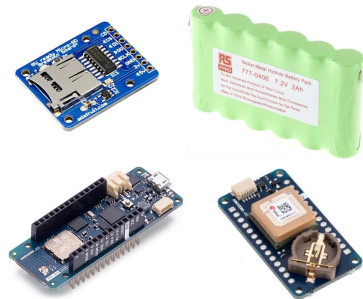




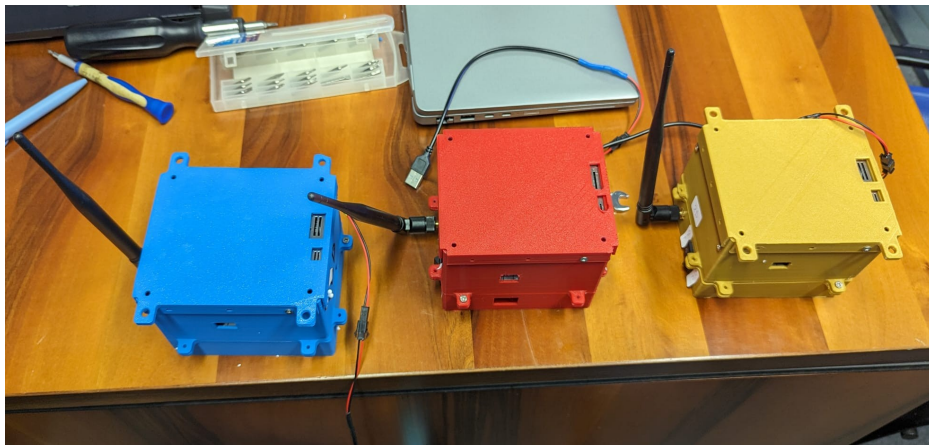
Sensor	Weight	Power	Resolution	Range	T90	Type
7S02-2000	8 g	25 mW	5 ppm	2000 ppm	<70 s	Electrochemical
7S02-100S	8 g	25 mW	0.05 ppm	100 ppm	<20 s	Electrochemical
7HCI-100	8 g	25 mW	1 ppm	100 ppm	<70 s	Electrochemical
7H	Sensor	Weight	Power	Resolution	Range	Type
	SPS30	26 g	275 mW	10 - 25 $\mu\text{g}/\text{m}^3$	1000 $\mu\text{g}/\text{m}^3$	Laser

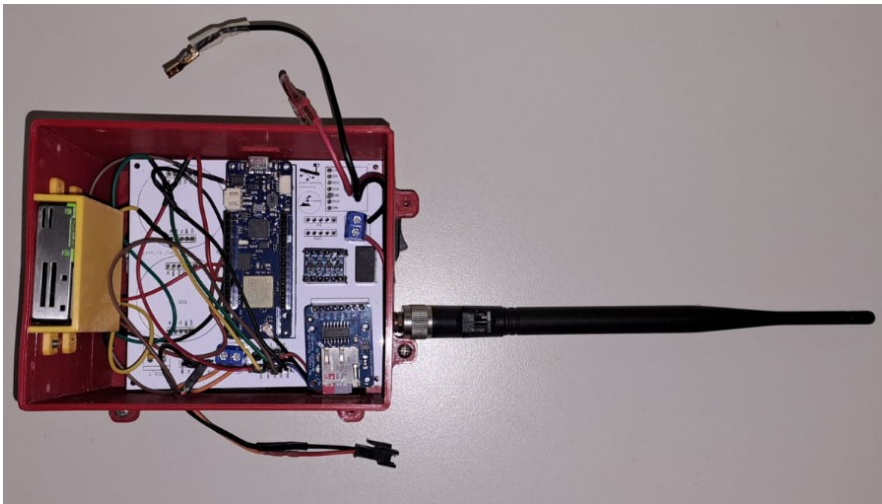
Sensor	Weight	Power	Resolution	Range	T90	Type
COzIR LP-5000	2.5 g	3.5 mW	30 ppm	5000 ppm	<30s	NDIR

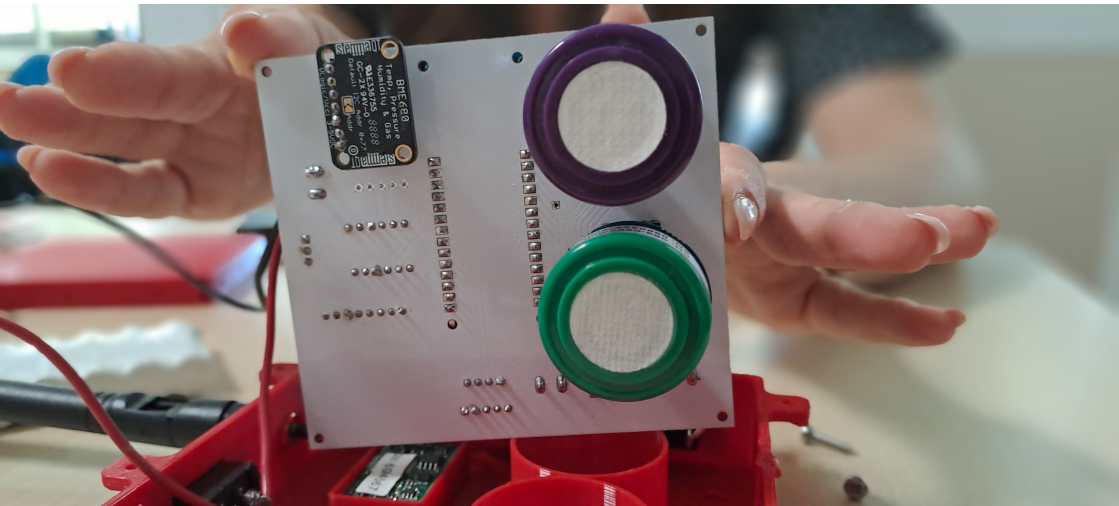
Sensor	Weight	Power	Count Rate	Range	Type
Alphasense N3	100 g	0.9 W	10000 p/s	0.35 - 40 μm	Laser

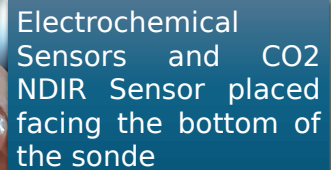


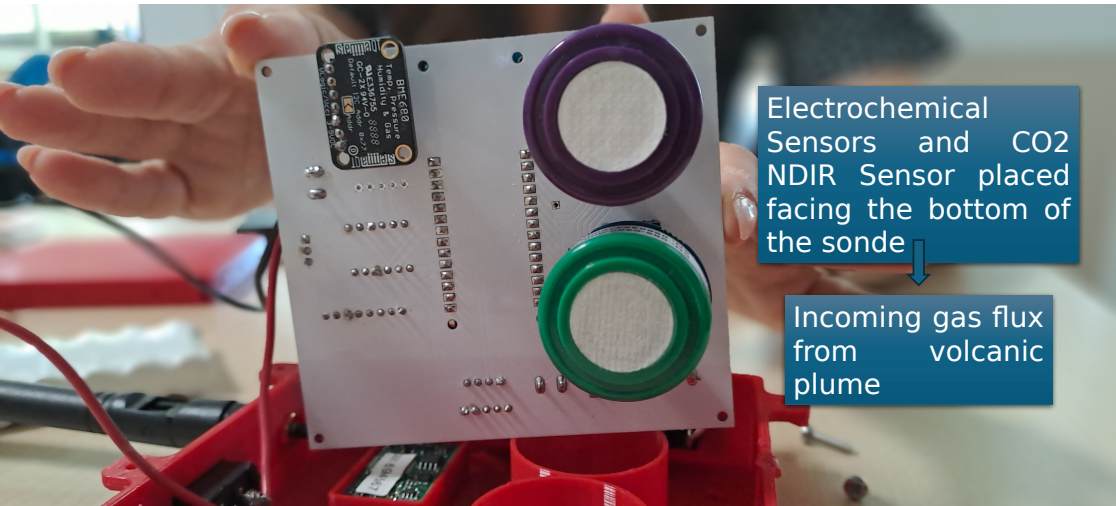
Sample Frequency	1 Hz
Telemetry Frequency	1 Hz
Battery Life	> 24 Hr
Weighth	450 g
Volume	140x117x95 mm
Material	3D Printed PLA







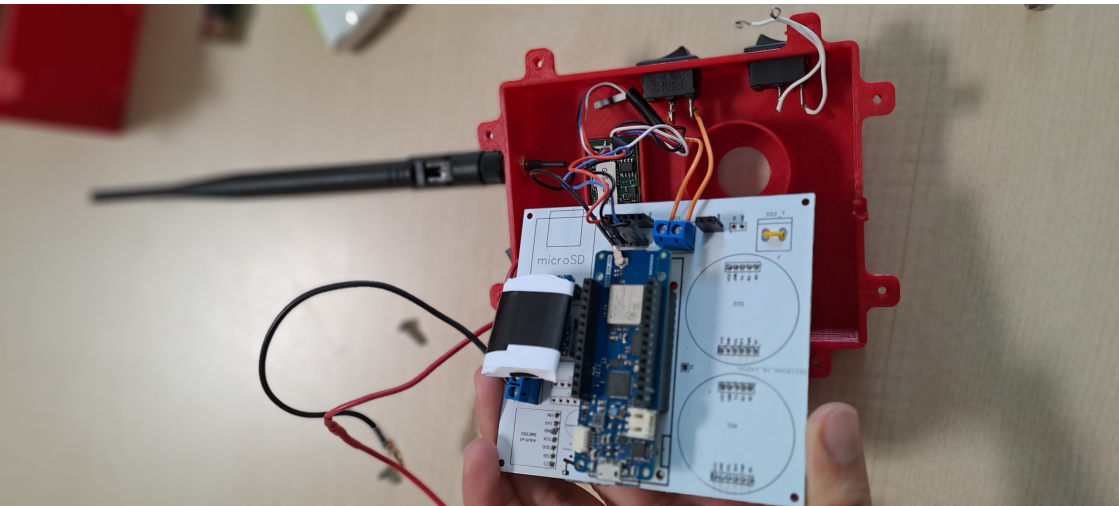


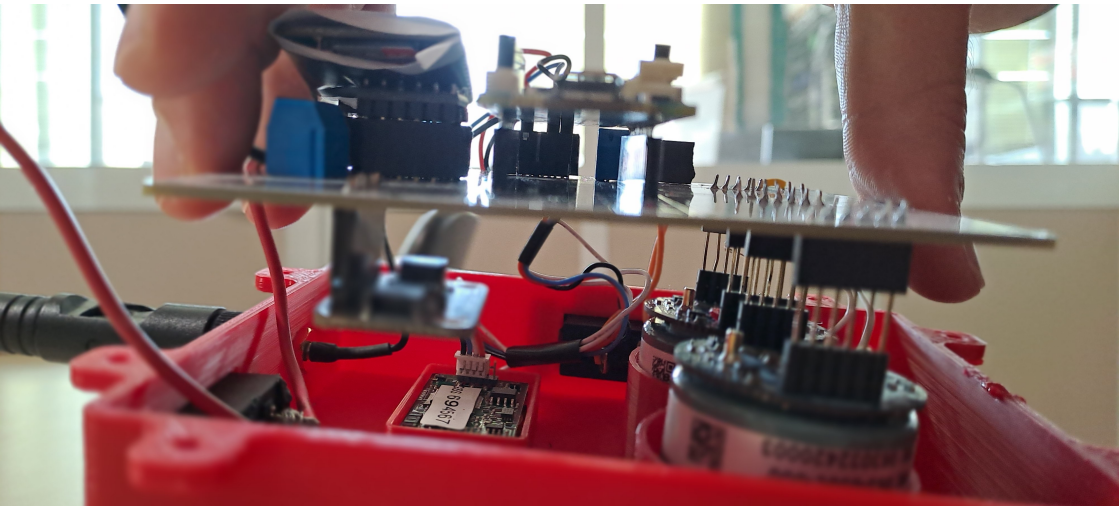


Electrochemical
Sensors and CO₂
NDIR Sensor placed
facing the bottom of
the sonde



Incoming gas flux
from volcanic
plume





SPS30 Inlet and Outlet faucets are facing the upper side of the sonde to avoid impinging flux on the fans



Battery placed on upper shelf for easy access and charging



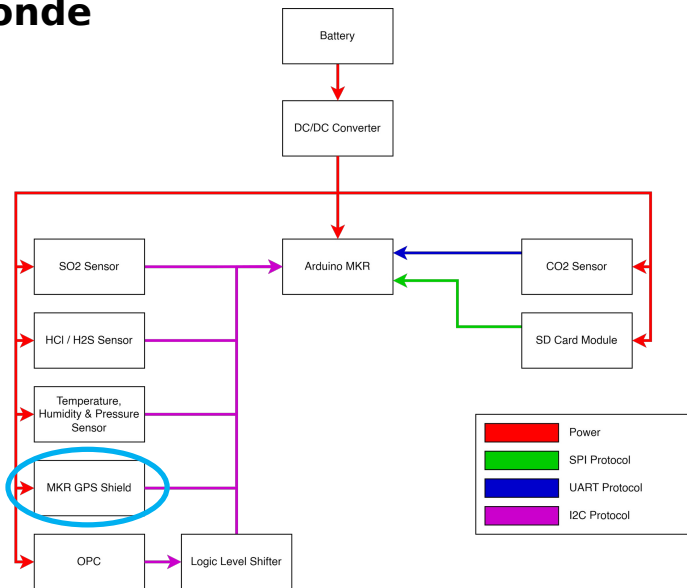
4h-stabilization needed to give the HCL sensor the required bias voltage between the electrodes

A switch that excluded the rest of the circuit during power up was implemented

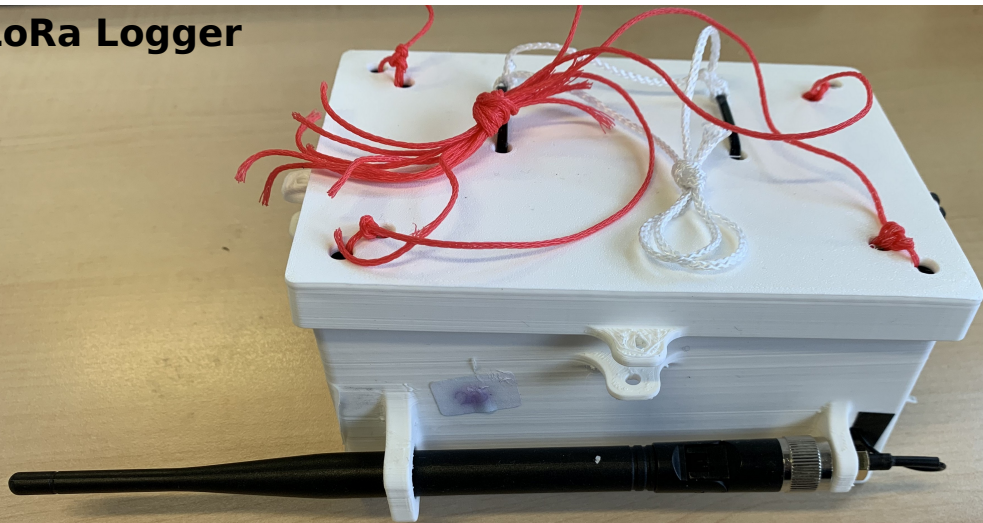
No longer necessary after the substitution with H₂S Sensor

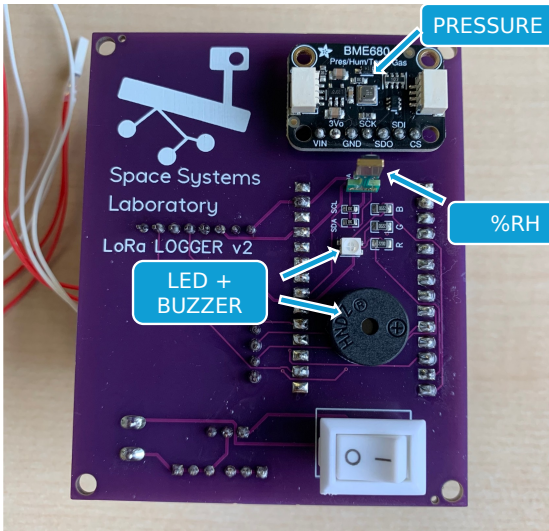


Volcanosonde V1.5

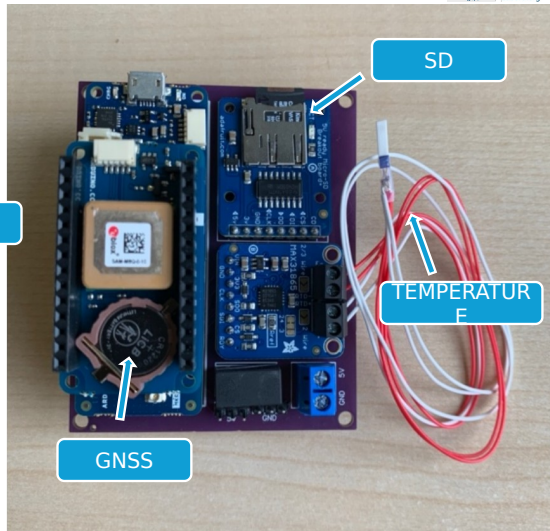


LoRa Logger

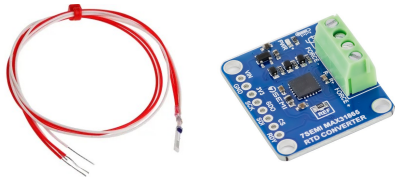




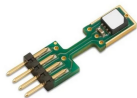
Bottom Part



Upper Part



Sensor	Weigth	Power	Count Rate	Range	Type
MAX31865 + PT100	10 g	15 mW	0.1°C	-40 - 105 °C / 0-100 %RH	Platinum RTD



Sensor	Weigth	Power	Count Rate	Range	Type
SHT85	7 g	1.5 mW	0.01 %RH	-40 - 105 °C / 0-100 %RH	Digital T/RH

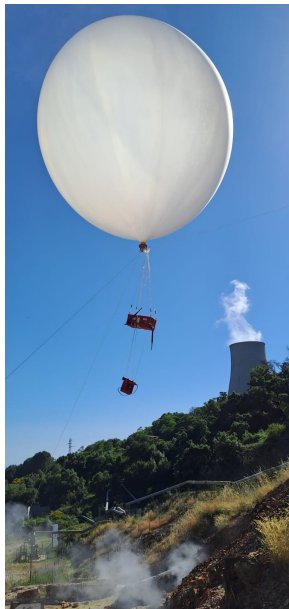


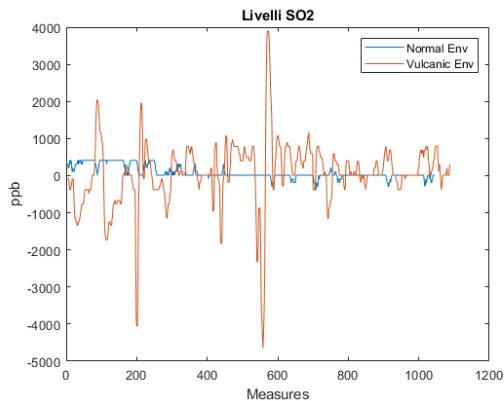
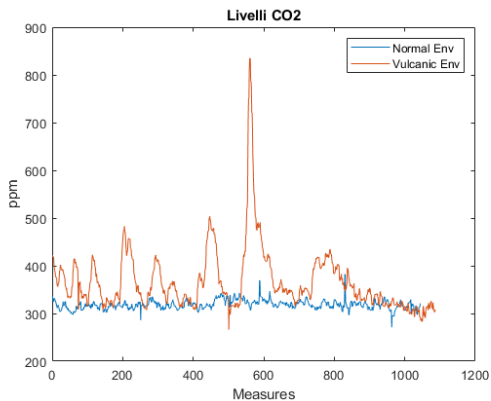
Sensor	Weigth	Power	Count Rate	Range	Type
BME680	5 g	4 mW	0.18 Pa	300 - 1100 hPa	MEMS

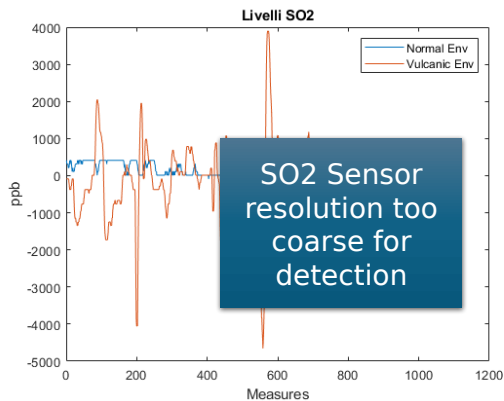
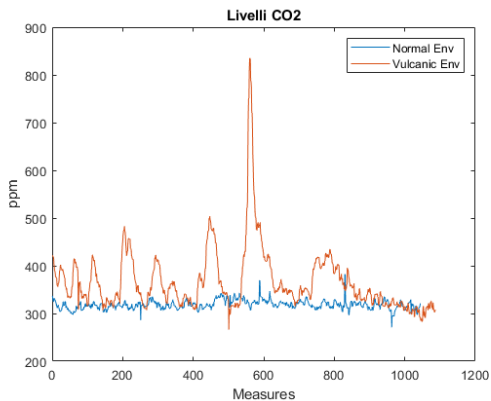
Parco delle Biancane 2024

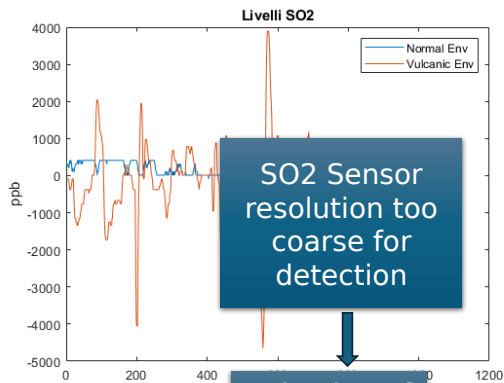
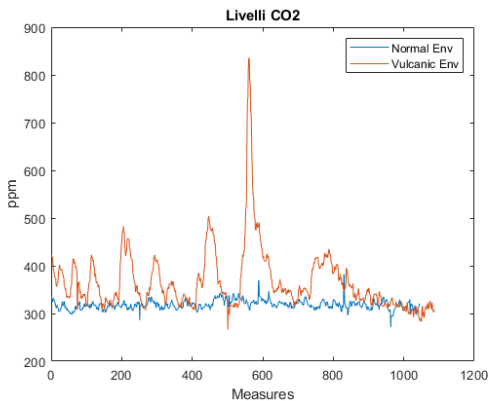










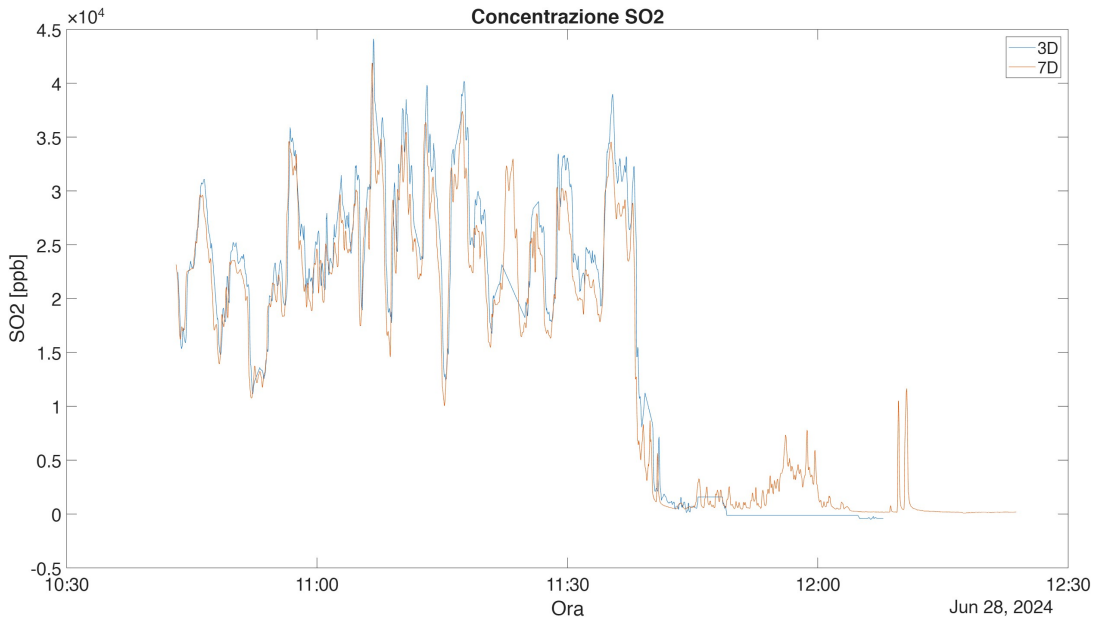


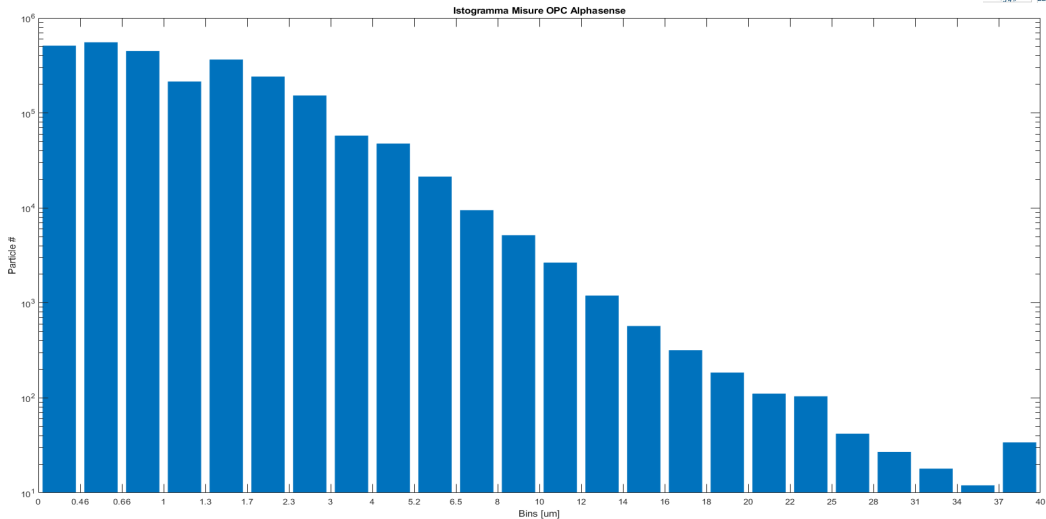
SO2 Sensor
resolution too
coarse for
detection

Selection of
another
model

Etna June 2024







Etna June 2024

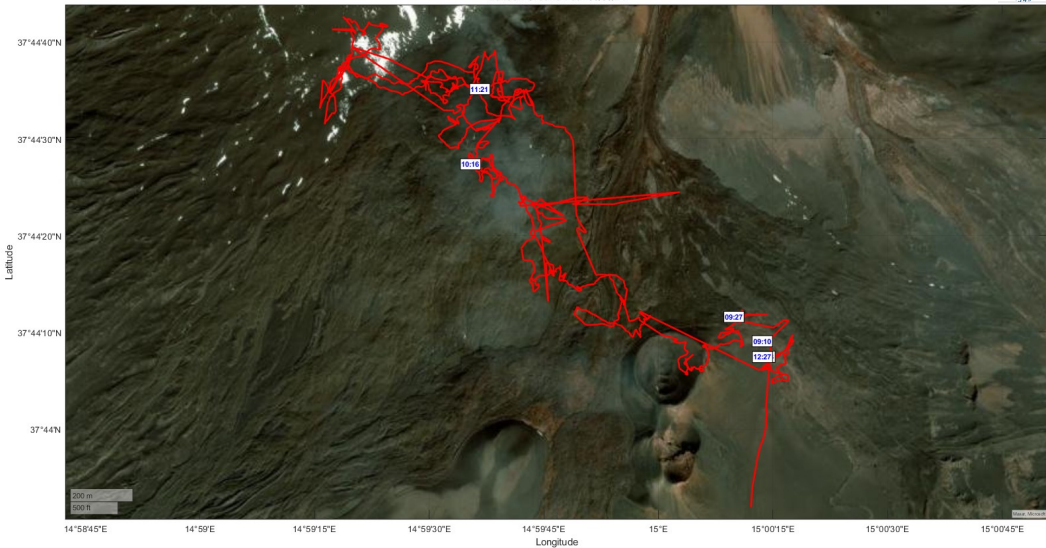
- First volcanic field qualification of the Volcanosonde
- Confirmed system functionality, exposed CO₂ calibration issues, and informed logistics for the August 2024 campaign.



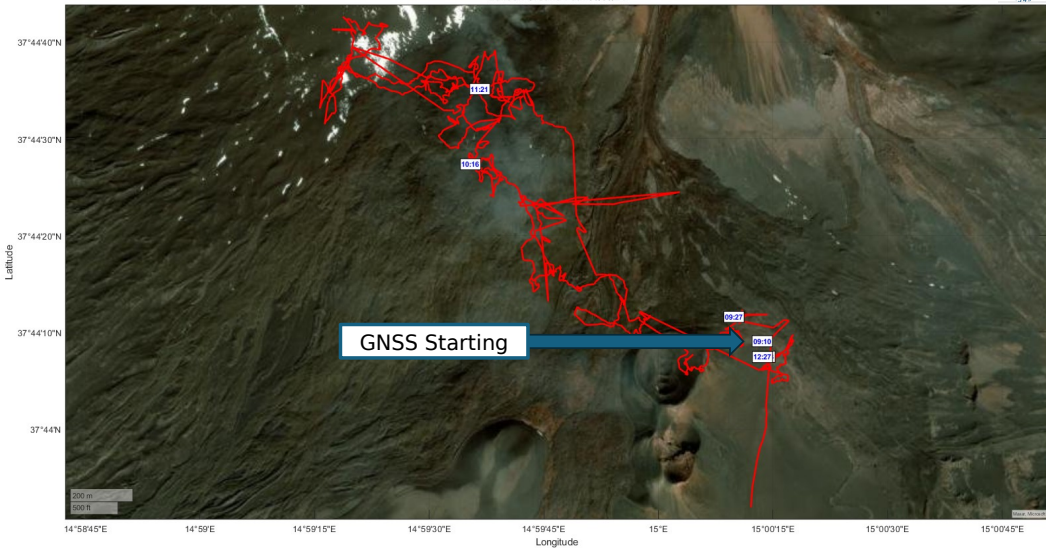
Etna August 2024



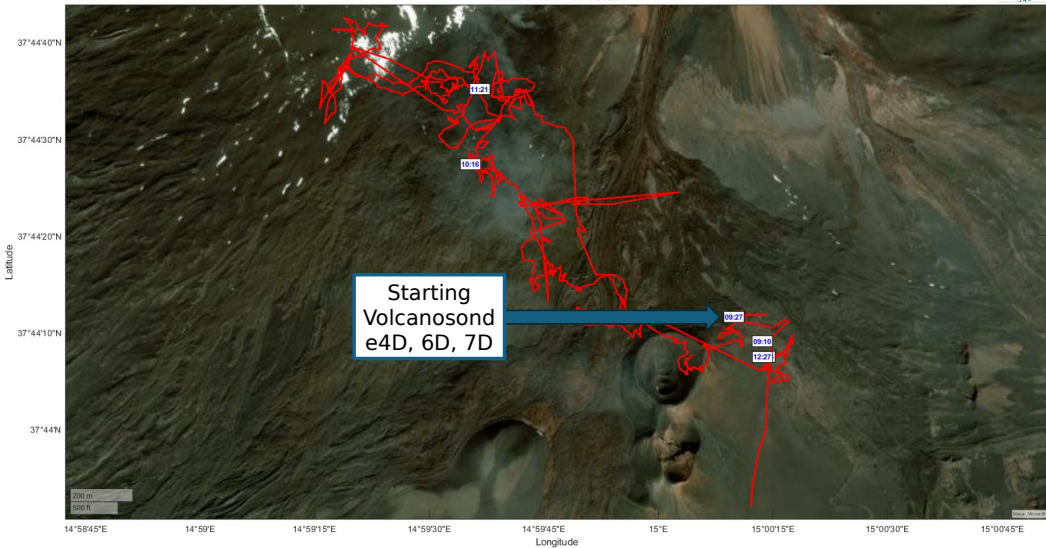
Balloon Ground Path 30/08/24



Balloon Ground Path 30/08/24



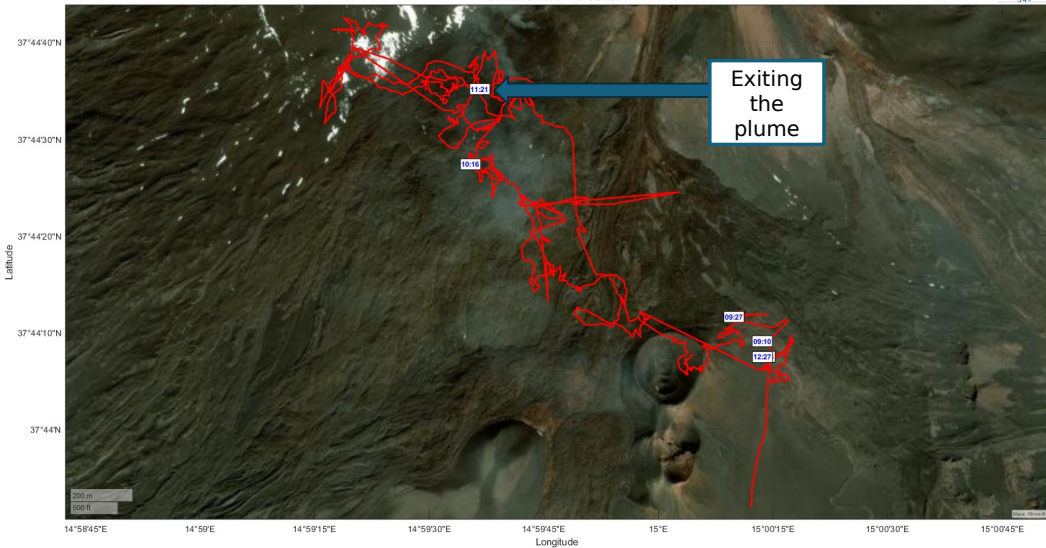
Balloon Ground Path 30/08/24



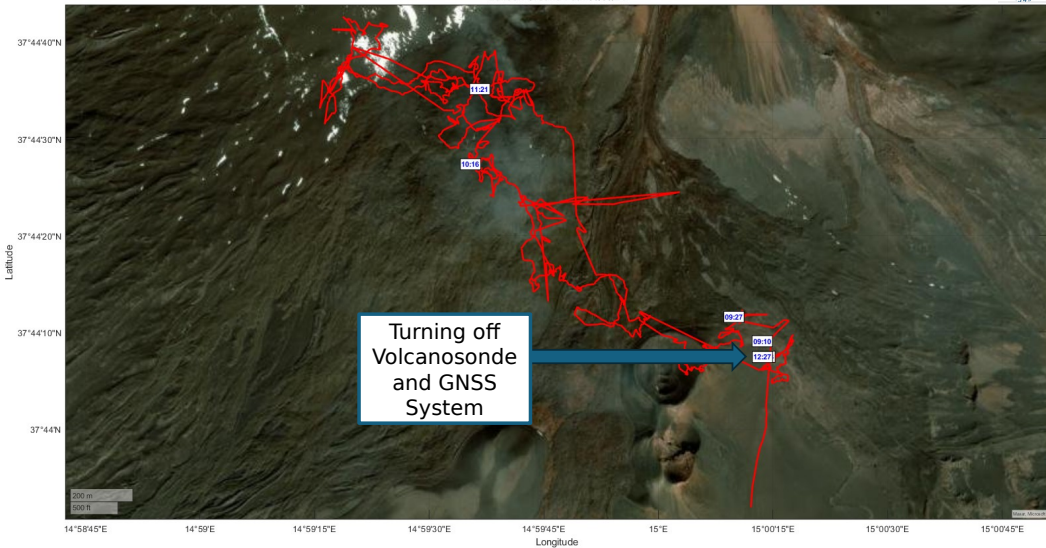
Entrance
in plume

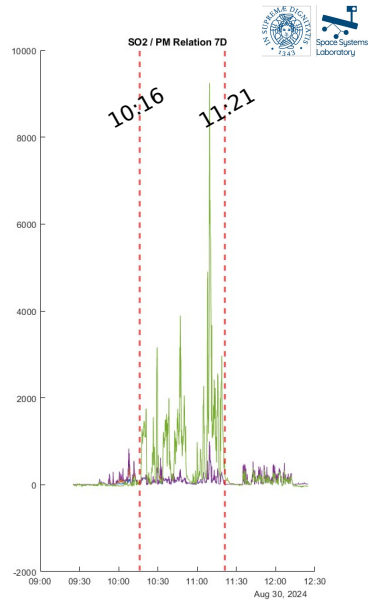
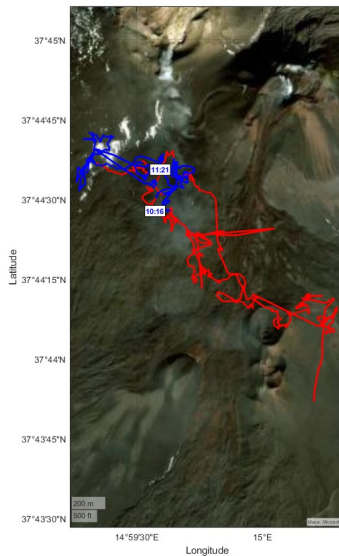
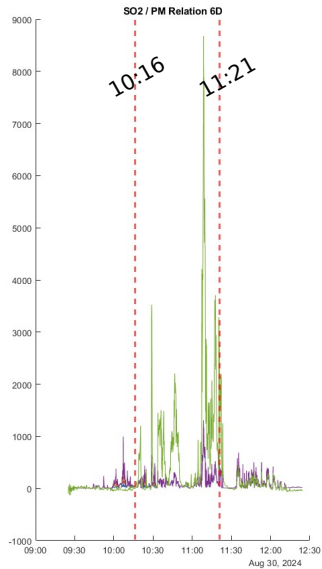


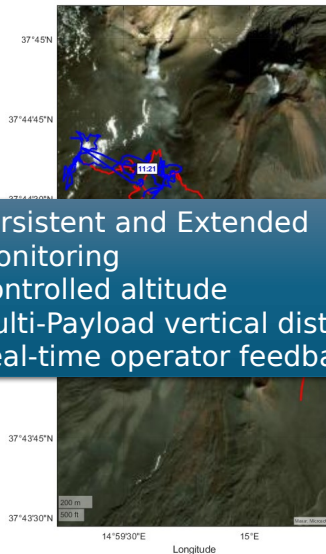
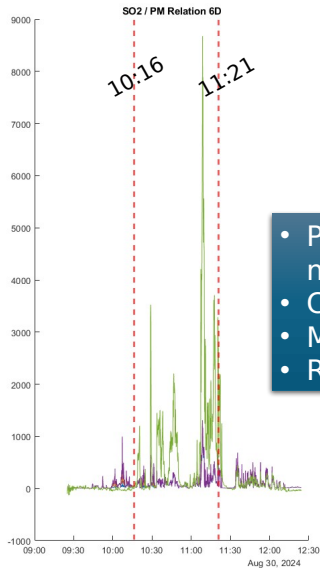
Balloon Ground Path 30/08/24



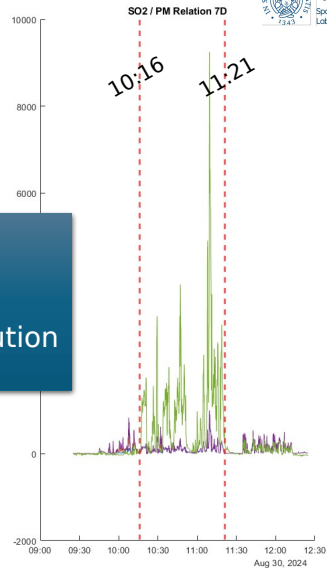
Balloon Ground Path 30/08/24

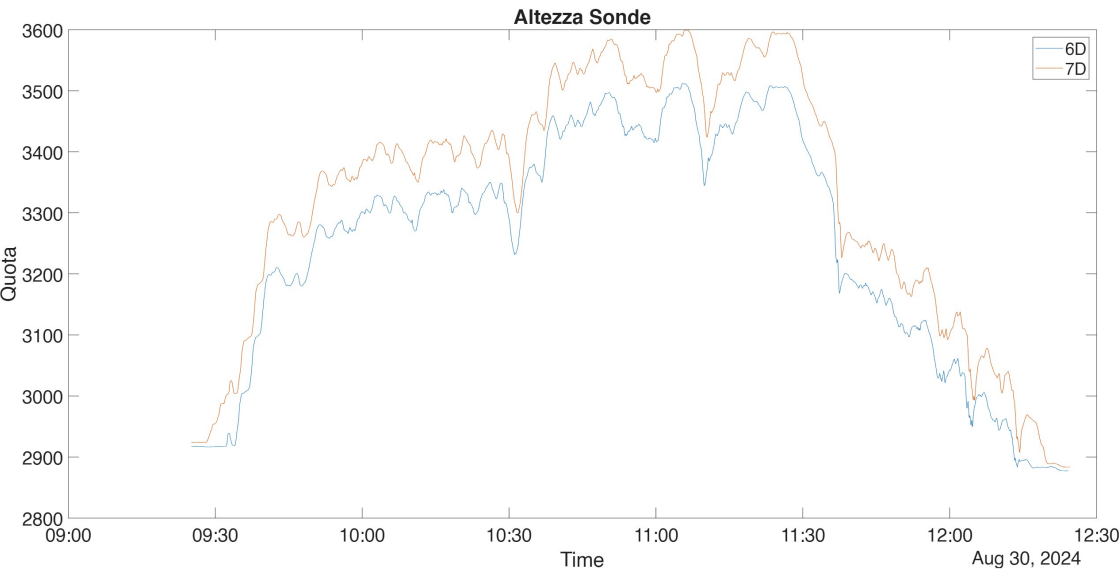


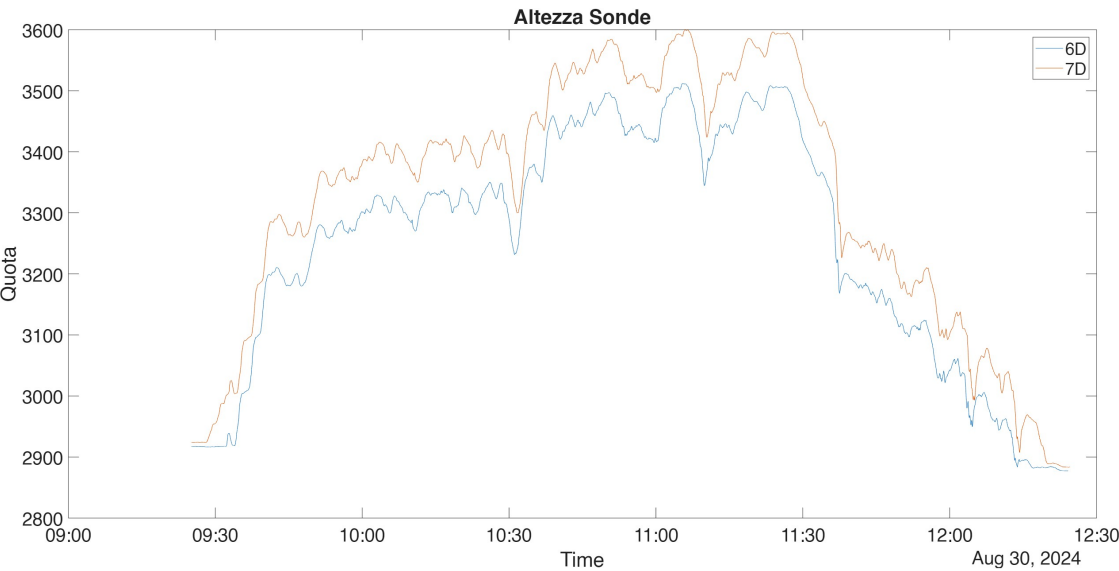




- Persistent and Extended monitoring
- Controlled altitude
- Multi-Payload vertical distribution
- Real-time operator feedback







Estimated Balloon Elevation:
400 m

Etna August 2024

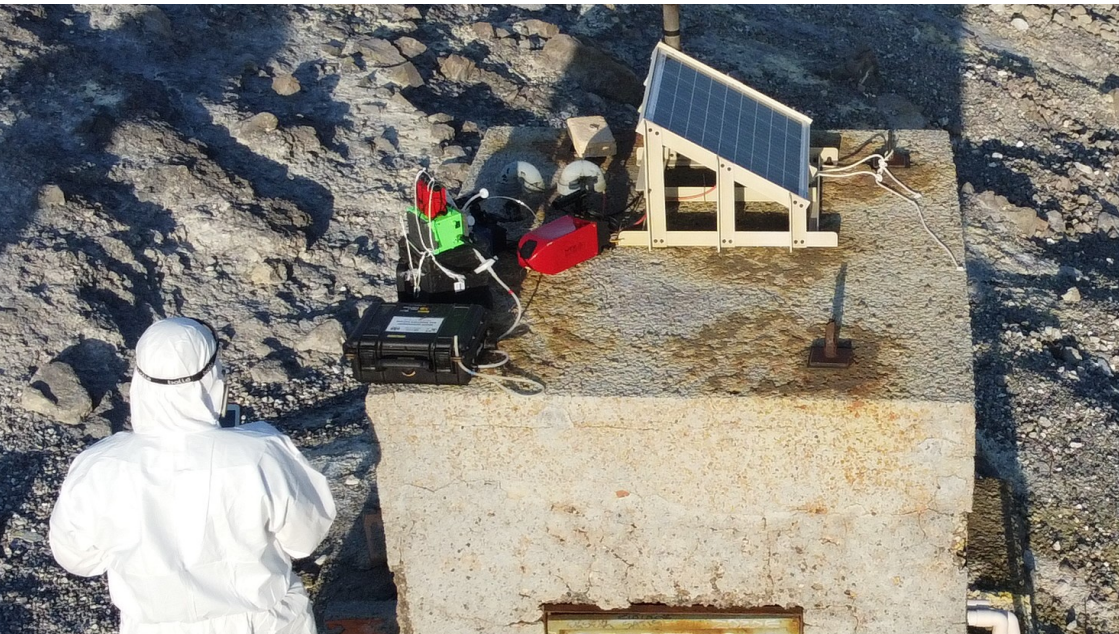
First full-scale validation of the balloon-borne platform. Tethered operation proved the most effective for persistent plume interception, while lift/drag ratio and dynamics of gases in the plume emerged as critical limitations.

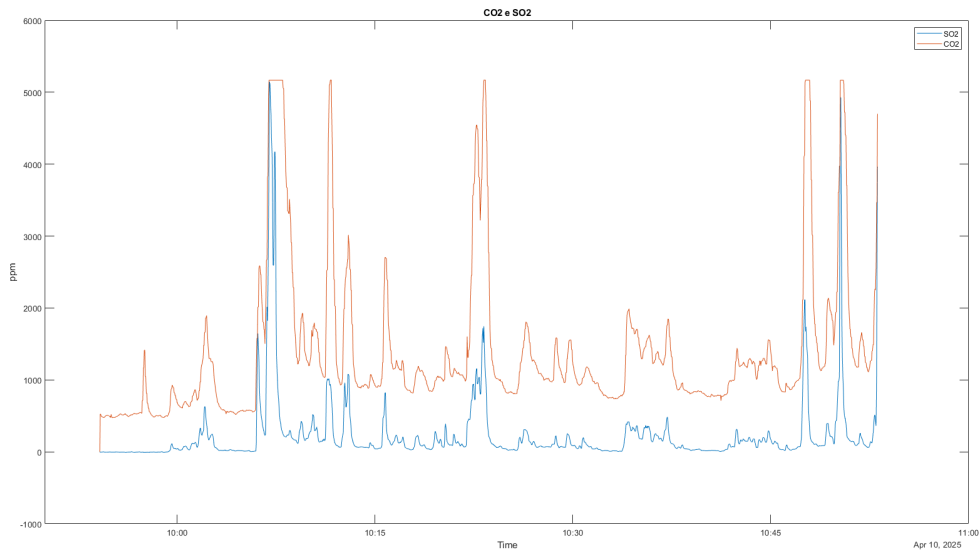


Vulcano April 2025









Vulcano April 2025

Comparative validation against mature multi-gas systems. Confirmed measurement reliability, with remaining differences mainly attributable to CO₂ sensor response time. Switching from HCl to H₂S sensor and test on the field of the latter



Demonstrating the effective modularity between different gases sensing sensors



Etna June 2025

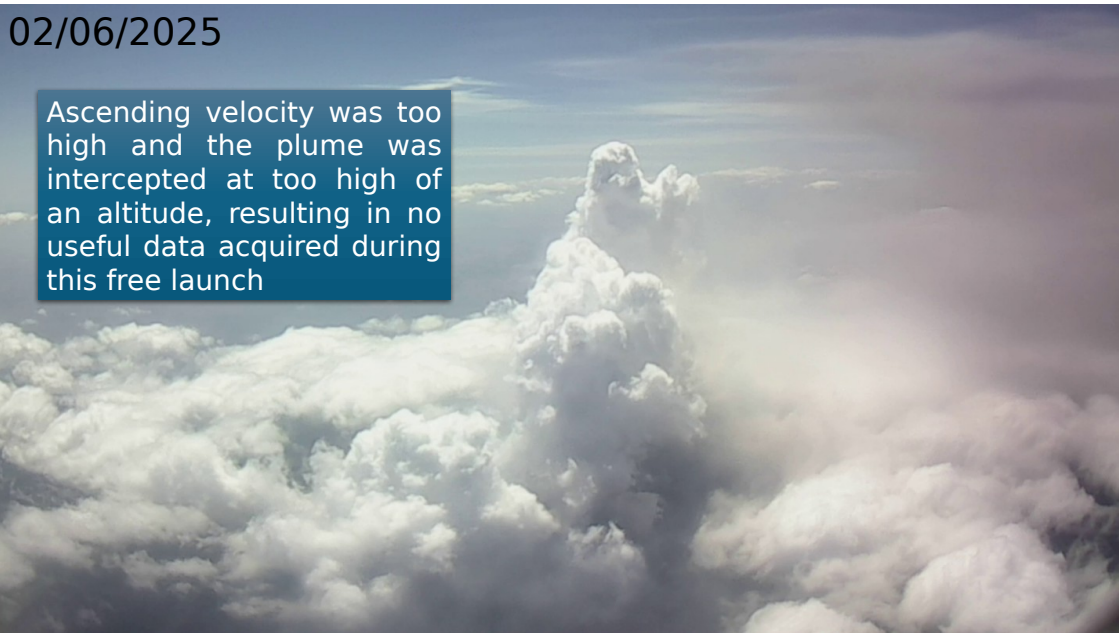


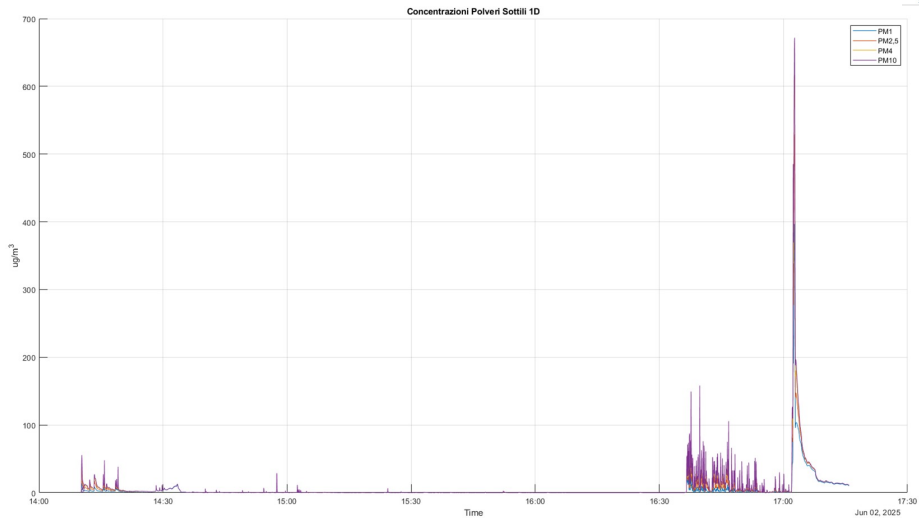
02/06/2025

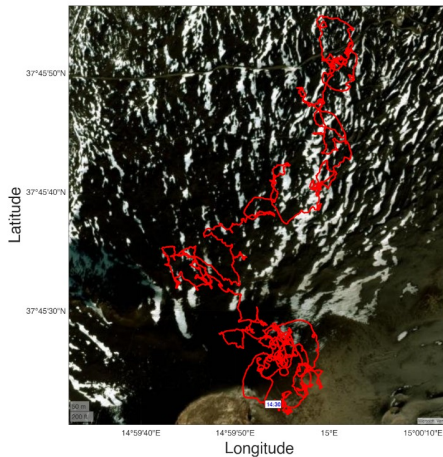
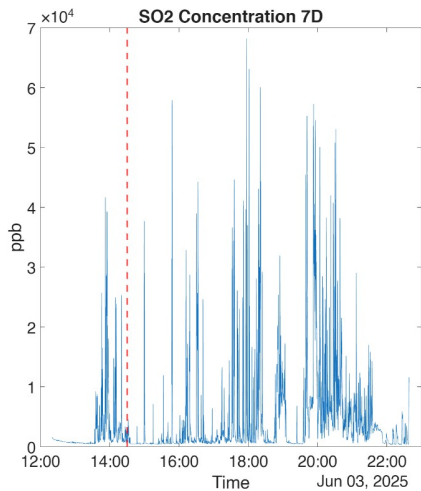


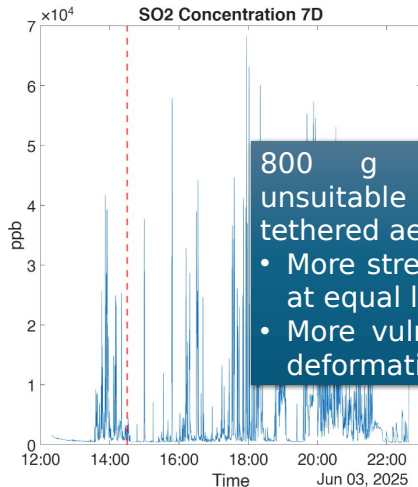
02/06/2025

Ascending velocity was too high and the plume was intercepted at too high of an altitude, resulting in no useful data acquired during this free launch



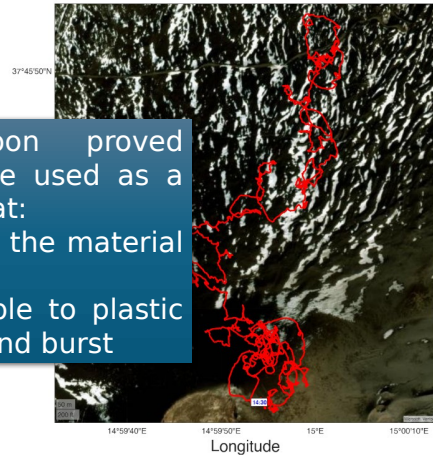




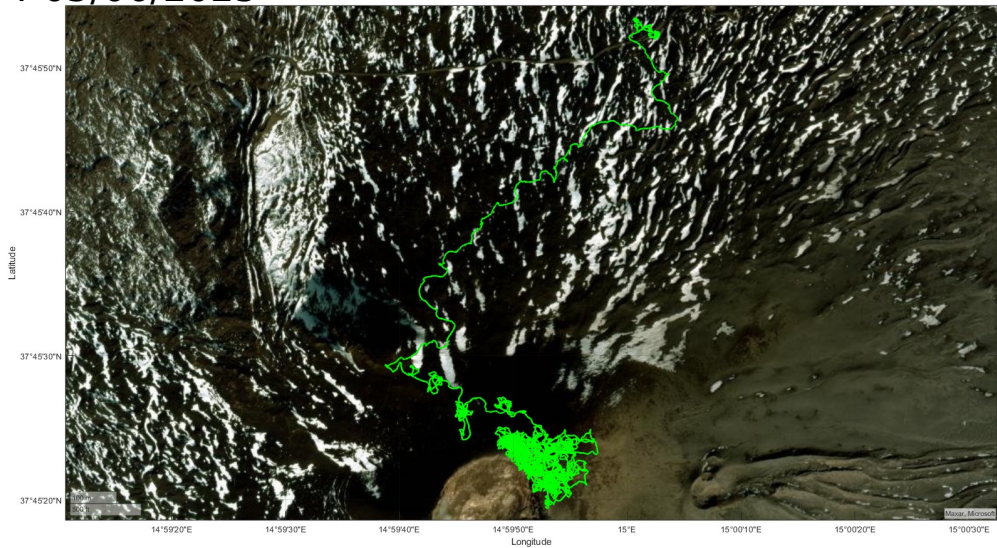


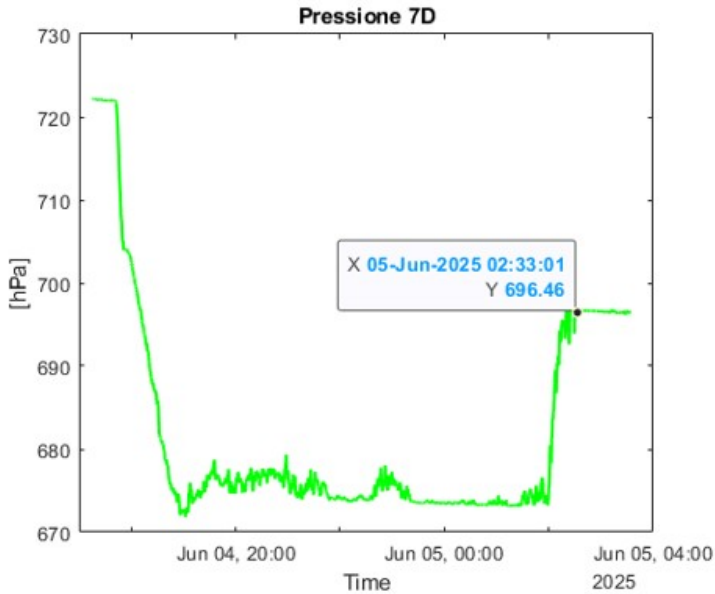
800 g balloon proved unsuitable to be used as a tethered aerostat:

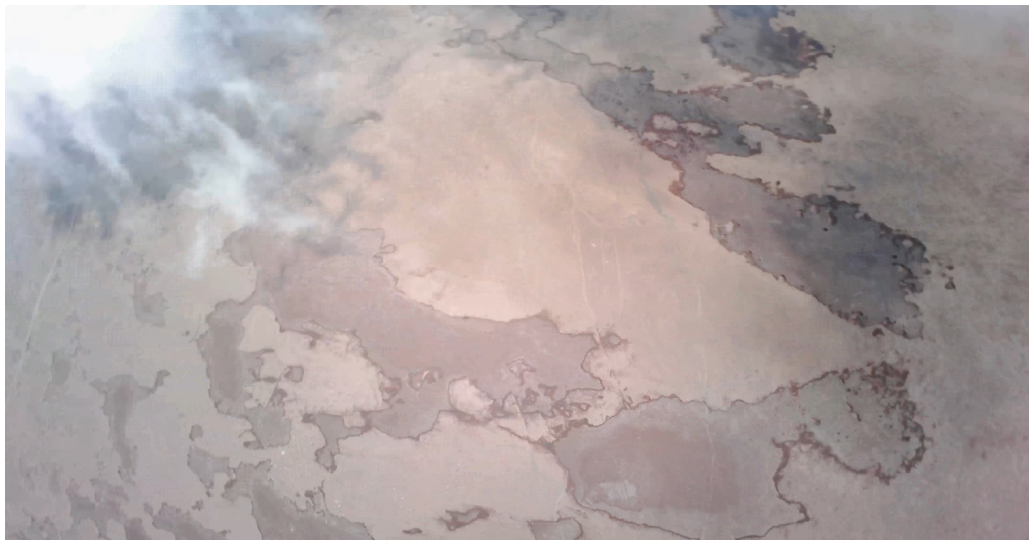
- More stress in the material at equal lift
- More vulnerable to plastic deformation and burst



04-05/06/2025



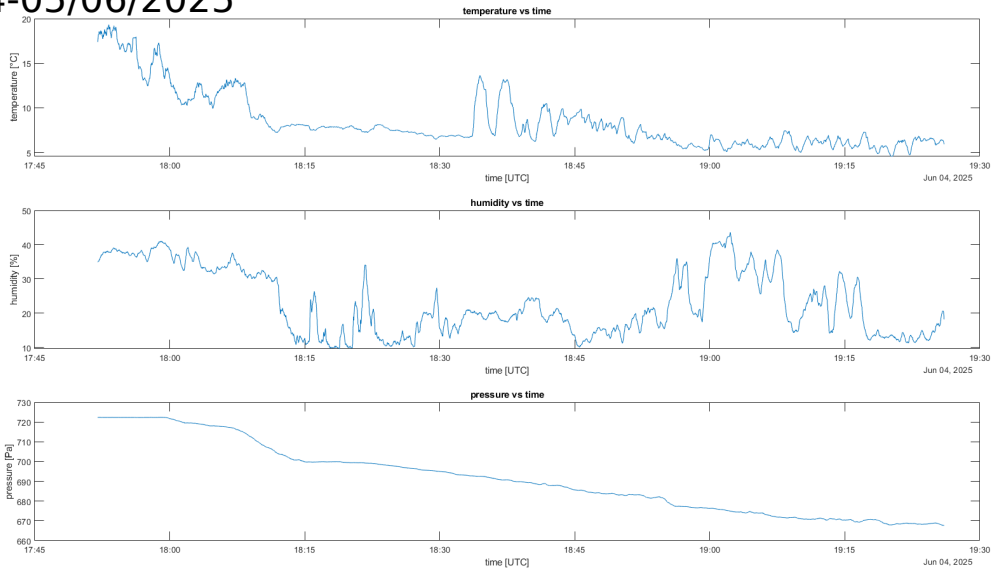




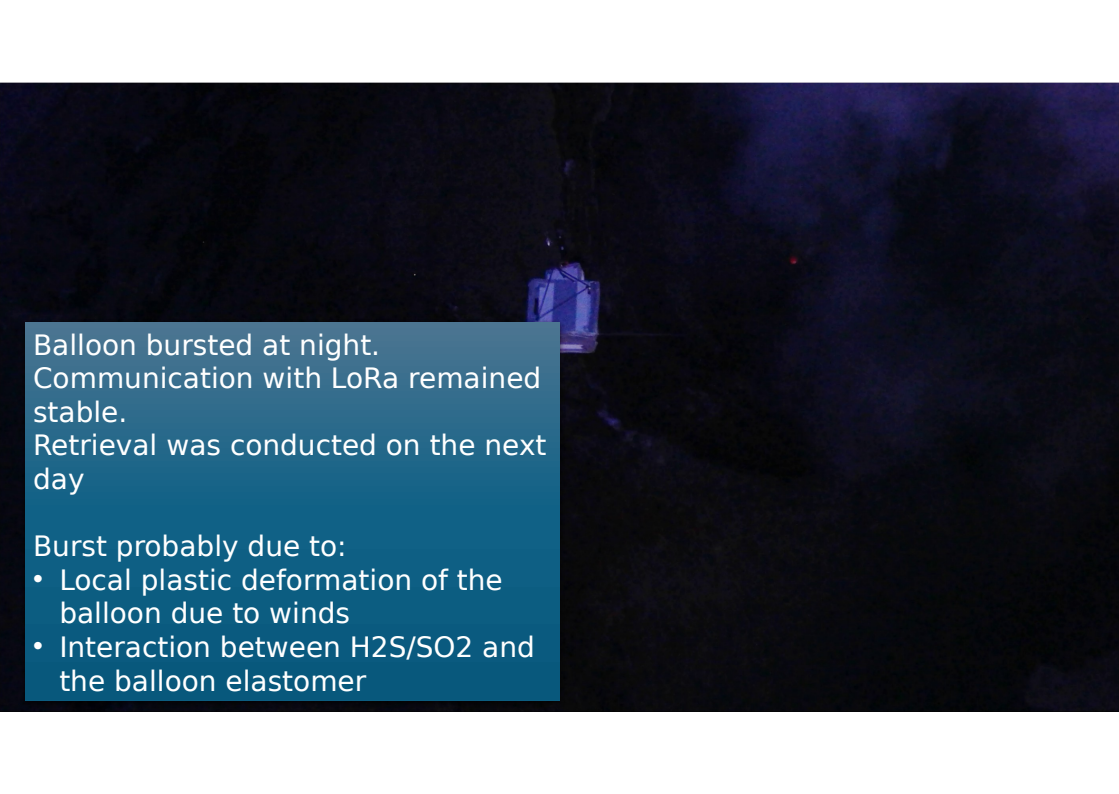
04-05/06/2025



04-05/06/2025







Balloon bursted at night.
Communication with LoRa remained
stable.
Retrieval was conducted on the next
day

Burst probably due to:

- Local plastic deformation of the balloon due to winds
- Interaction between $\text{H}_2\text{S}/\text{SO}_2$ and the balloon elastomer

06/06/2025



Etna June 2025

Confirmed the maturity of the tethered platform for multi-payload plume sampling.

Showed that 800 g balloons are insufficient, while latex degradation and lift management remain the main operational constraints.

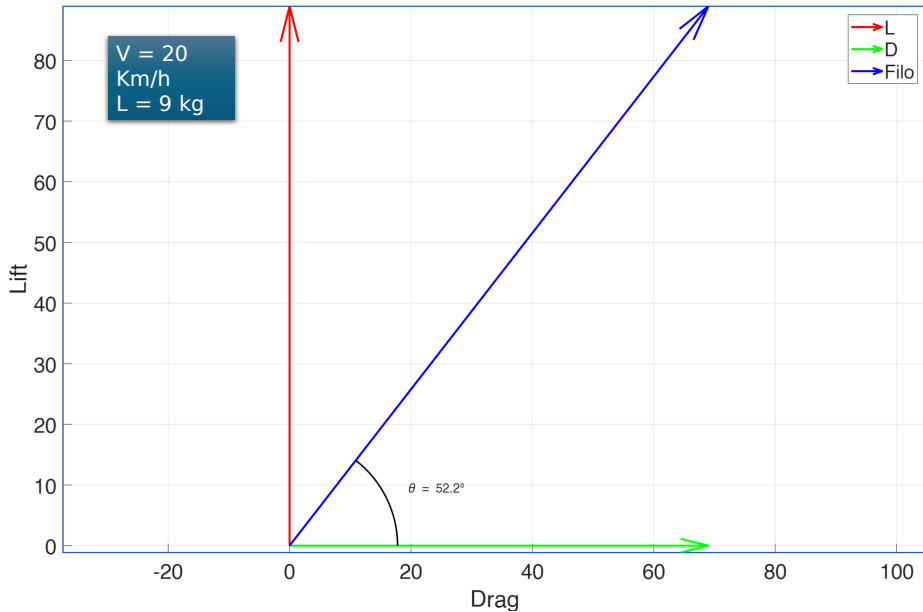


Etna October 2025

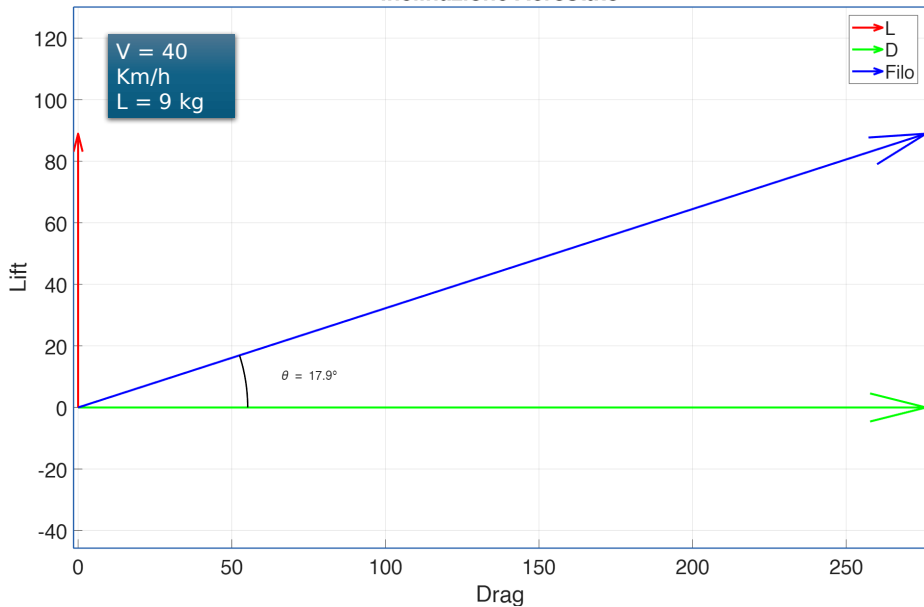




Inclinazione Aerostato



Inclinazione Aerostato







Etna October 2025

Extreme-wind stress test of the tethered platform. Defined operational wind limits and reinforced the need for improved balloon design and aerodynamic robustness.



Summary: Campaign Test Results

- **Biancane 2024** → early validation / sensor tuning
- **Etna Jun 2024** → first time in target environment
- **Etna Aug 2024** → first full-scale deployment
- **Vulcano Apr 2025** → comparison with reference instruments
- **Etna Jun 2025** → extended dataset + operational limits
- **Etna Oct 2025** → harsh-wind limit testing

Conclusions and Lessons learned

Three Critical Factors in the system:

- Sensor response time vs plume dynamics
- Wind sensitivity
- Balloon material durability



Future Fixes

- Choosing sensors with different working principles
- Increasing Lift / Reducing Drag
- Considering different aerostat types

- Small Scale Super Pressure Balloon - Drag Minimizing Shape
- Small Scale Super Pressure Balloon - Lift Increasing attitude-controlled system with propellers



Conclusions and Lessons learned

- The VOLANDO project successfully demonstrated the feasibility of the proposed low-cost in-situ measurement system, consisting of a tethered aerostat and a lightweight modular sonde, or Vulcanosonde.
- The tethered balloon configuration was found to be particularly useful for controlled, long-duration experiments, as it allows stable plume sampling and real-time monitoring without the aerodynamic perturbations associated with drone operations.
- Progressively, field experiments confirmed the effectiveness of the measurement chain and the methodology, as well as the ability of the platform to collect relevant gas and particulate matter data in an active volcanic environment.
- The operational limitations of the proposed approach were found to be related to the wind and balloon material durability issues.
- At the light of the results and of the lesson learned from present study, its findings are considered to be an important contribution to the development of even more reliable, resistant, and flexible balloon-based monitoring systems.

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Thank you for your Attention!



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