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ITINERIS

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DEVELOPMENT OF AN AEROGEOPHYSICAL INFRASTRUCTURE

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1. INTRODUCTION

Here we present **Deliverable 7.7** in the context of **WP7** of the *ITINERIS* project, which entails the integration of Research Infrastructures and activities in the **Geosphere and Land Surface** domains. The deliverable describes the ongoing implementation of a new Italian **Aerogeophysical Research Infrastructure** launched by the National Institute of Oceanography and Applied Geophysics –OGS and specifically by its Geophysics Section. This activity is a new Italian contribution to the *European Facility for Airborne Research (EUFAR)*, an established collaborative network dedicated to advancing interdisciplinary airborne research in environmental science.

So far, OGS has contributed to EUFAR with its fixed wing and drone-based remote sensing capabilities. These enable mapping and research applications mainly for surface studies. Our goal within ITINERIS is to **acquire a suite of instrumentation to facilitate an important expansion of the scope of future airborne research and scientific services to the subsurface**.

We present an overview of the new aerogeophysical infrastructure we are developing within EUFAR. To achieve this, we include a description of the individual instrument suites we are currently acquiring to enable new **aeromagnetic, airborne gravity and ground penetrating radar** research.

2. DEVOLOPMENT OF A NEW AEROGEOPHYSICAL INFRASTRUCTURE IN EUFAR

The EUropean Facility for Airborne Research (EUFAR) brings together operators active in managing atmospheric and remote-sensing airborne platforms and instruments with the scientific user community, ranging from internationally recognised experts in the field to mid and early-stage researchers, interdisciplinary data users and stakeholders.

EUFAR was born in year 2000, to meet the requirement of creating a more centralised network for the interdisciplinary airborne research community in Europe, thus better supporting scientists, by granting them access to research aircraft, instruments and capabilities not easily accessible in their own countries. The goal was to facilitate scientists from all over Europe and offer them a greater chance to carry out various atmospheric and remote sensing measurements onboard research aircraft. EUFAR aimed to link scientists with research facility operators. It formerly actively supported international collaboration by winning various EU projects, which successfully provided transnational access and funding for flight hours and for travel and subsistence during the campaigns.

EUFAR has changed over the last two decades, introducing new activities and objectives that currently focus more on networking and airborne data portal development for environmental research in Europe. EUFAR continues to help improve operational environments for conducting innovative airborne research. Current activities range from organising seminars, expert workshops, and serving as an interactive information hub, to maintaining a data archive, and developing tools and standards to aid the collection, processing and analyses of airborne data.

In 2024, EUFAR contributed to the submission of an enhanced airborne infrastructure EU proposal **AIRLIFTS** that aimed to include not only aircraft but also drones and balloons. As the proposal was not funded by the EU Commission a smaller scale preparatory EU COST action was prepared (currently in evaluation). EUFAR currently has 12 member organisations and 4 partners, mostly focussing on atmospheric research and remote sensing. OGS is a member organisation that contributes with its remote sensing aircraft and instrumentation and Ferraccioli's activities on the Executive Committee. However, EUFAR currently lacks aereogeophysical infrastructures. This hampers launching new subsurface research efforts and/or services. We aim to help fill this gap in ITINERIS by acquiring the suite of new instruments that are described hereafter.

Figure 1 – The EUropean Facility for Airborne Research (EUFAR) and its current members (https://www.eufar.net/).

Figure 2 – The OGS fixed wing airborne platform (a Piper Seneca III), which is currently part of the remote sensing infrastructures within EUFAR.

2.1 Aeromagnetic Instrumentation

The aeromagnetic instrumentation suite we are acquiring in ITINERIS is composed of 5 items:

Item 1

2 **High-resolution Cesium Magnetic Sensors** for installation on an aircraft. This is the key instrumentation that measures the Total Magnetic Intensity – TMI.

After data corrections have been applied aeromagnetic anomalies related to both surface and subsurface geological heterogeneity can be computed.

Item 2

1 **Fluxgate Magnetometer** (3 components) for magnetic compensation on the aircraft and compensation software (post-processing).

This instrument is required to correct for the magnetic effects of the aircraft itself that can be detrimental when calculating aeromagnetic anomalies related to geological sources. While this sensor is not required if the Cs magnetometers are deployed in towed-bird configuration it is essential for enabling fixed-wing installations.

Item 3

1 **Aeromagnetic Data Acquisition and Positioning System**. This comprises:

Power supply unit for the aeromagnetic sensors;

Acquisition system of TMI aeromagnetic data from the cesium sensors and the 3-component fluxgate magnetometer and GPS and onboard radar altimeter data;

Navigation module with pre-planning software for aeromagnetic flights;

Real-time display of magnetic and positioning data for the operator to monitor and perform initial quality control of the aeromagnetic data;

Positioning module for operator and pilot during the flight, including software.

Item 4

2 **GPS receivers and antennas** (one on the aircraft and one as a base station) configured with the aeromagnetic acquisition system.

GPS receivers onboard are essential for positioning, while a base station enables more accurate differential positional solutions to be calculated, typically in post-processing mode.

A GPS base station is essential for airborne gravity (see section 2.3) data acquisition, which typically requires higher accuracy positioning, especially when compared with reconnaissance aeromagnetic surveying.

Item 5

1 **Magnetic Base Station**

This instrument is required because the magnetic field is affected by diurnal variations that can be confounded with geological sources of aeromagnetic anomalies if not appropriately corrected for.

CS-3 SCINTREX HIGH SENSITIVITY CS MAGNETOMETER SENSOR

Operating Principle:	Self-oscillation split-beam Cesium Vapor (non-radioactive Cs-133)
Operating Range:	15,000 to 105,000 nT
Gradient Tolerance:	40,000 nT/metre
Operating Zones:	15° to 75° and 105° to 165°
Hemisphere Switching:	a) Automatic b) Electronic control actuated by the control voltage levels (TTL/CMOS) c) Manual
Sensitivity:	0.0006 nT √Hz rms.
Noise Envelope:	Typically 0.002 nT P-P, 0.1 Hz bandwidth
Heading Error:	± 0.2 nT (inside the optical axis to the field direction angle range 15° to 75°and 105° to 165°)
Absolute Accuracy:	<2.5 nT throughout range
Output:	a) continuous signal at the Larmor frequency which is proportional to the magnetic field (proportionality constant 3.49857 Hz/nT) sine wave signal amplitude modulated on the power supply voltage b) square wave signal at the I/O connector, TTL/CMOS compatible Information Bandwidth
Sensor Head:	Diameter: 63 mm (2.5”) Length: 160 mm (6.3”) Weight: 1.15 kg (2.6 lb)
Sensor Electronics:	Diameter: 63 mm (2.5”) Length: 350 mm (13.8”) Weight: 1.5 kg (3.3 lb)
Cable, Sensor to Sensor Electronics:	3m (9’ 8”), lengths up to 5m (16’ 4”) available
Operating Temperature:	-40°C to +50°C
Humidity:	Up to 100%, splash proof
Supply Power:	24 to 35 Volts DC
Supply Current:	Approx. 1.5A at start up, decreasing to 0.5A at 20°C
Power Up Time:	Less than 15 minutes at -30°C

Table 1 – Technical specifications of Scintrex Cs-3 magnetic sensors.

Figure 3 – Aeromagnetic sensors and data acquisition system.

Figure 4 – Magnetic Base Station (Geometrics) to monitor and correct for diurnal variations in the magnetic field.

IMPAC (Nuvia) Survey navigation with drape profile option and Data acquisition for a variety of sensors.

- Rack-mountable airborne data acquisition system operating under Windows OS
- Multicore CPU, SSD hard drive, analog inputs, and power interface for multiple type of detectors
- Imbedded MMS-8 magnetometer processor module with post-processing magnetic compensation software
- Imbedded navigation module - provides 2D and 3D navigation capability
- Color LCD touch screen (operator screen) display and keyboard
- Pilot Guidance Unit (PGU) – cockpit mountable 7" screen providing dedicated survey navigation information to pilots
- Multiple instrumentation interfaces
- Data recording directly to solid-state hard disk drive
- Autonomous Mode: No Operator required
- Data Acquisition software: AGIS (Airborne Geophysical Information System)
- CPU - 4th Gen Intel® Core™ Dual and Quad Core; BGA1364
- Magnetometer Sensor Input: 2 CS & 1 Fluxgate
- Realtime and post processing Mag compensation
- Interface for Multiple Sensors: 4 X USB (2x frontside, 3x backside), 8x RS232 serial ports
- Eight 16-bit differential analog inputs
- GPS input and 2 buffered 1-PPS outputs for time synchronization
- Multiple Ethernet connections
- 28V DC power input
- Weight: 6.5 Kg
- Rack mountable

Table 2 – Technical specifications of the IMPAC aeromagnetic and navigation data acquisition system.

MAGNETOMETER

Self-oscillating split-beam Cesium Vapor (non-radioactive).

Magnetometer Operating Range: 20,000 to 100,000 nT.

Operating Zones: The earth's field vector should be at an angle greater than 10° from the sensor's equator and greater than 10° from the sensor's long axis. Automatic hemisphere switching.

Noise/Sensitivity: $< 0.004\ nT/\sqrt{Hz}_{rms}$. (SX (export) version: $0.02\ nT/\sqrt{Hz}_{rms}$).

GPS Receiver: Time accuracy: 20ns, RMS, max. data rate; 1 Hz.

Data Logger: Serial logger, removable military grade USB memory stick or Android device.

Data Format: ASCII, MS Windows PC compatible, FAT16 file format.

Capacity: 21 days using 1 Gb USB memory stick while recording at 10 Hz rate with GPS receiver output set to provide GPRMC data sentence.

Resolution: 0.00 1nT

MECHANICAL / ENVIRONMENTAL

Storage Temperature: -45° C to +70° C (-48° F to +158°F).

Operating Temperature: -35° C to +50° C (-30° F to +122° F).

Senor Cable Length: 0.9 m (3 ft).

Electronics Module Dimensions: DIA: 7 cm; L: 38.7 cm; Weight: .91 kg (15.25 x 2.75 in; 2 lbs.)

Sensor Dimensions: DIA: 7 cm; L: 17.2 cm; Weight: .82 kg with cable. (6.75 in x 2.75; 1.8 lb).

Weatherproof: O-Ring sealed for operation in the rain and/or 100% humidity.

Power: 10 to 36 VDC, 30 Watt. or 110-220VAC (50-60hz).

Standard Accessories*: 110-220 VAC (50-60hz) power supply, USB-Flash drive with user software and manuals, tripod, staff kit, sensor clamp, AC cord, battery clip, shipping/storage case.

Table 3 – Technical specifications of the Geometrics magnetic base station.

2.2 Aeromagnetic Drone

As part of the ITINERIS project we are acquiring a High-Resolution Aeromagnetic sensor installed on a drone (MagArrow produced by Geometrics), complete with a power supply unit, navigation data acquisition system, flight planning system, and remote aeromagnetic data quality control (post-mission option). The MagArrow will be attached to a UAV (see specs below).

The very high sample rate (1000 Hz) and synchronized on-board GPS allow it to function independently of UAV software and assuming speeds up to 10 m/s magnetic data can be collected every 1 cm revolutionising ultra-high resolution magnetic surveying for environmental applications.

The MagArrow is engineered to simplify surveys that are inherently difficult due to the various limitations of pilot-on-board surveys and ground surveys.

The MagArrow is a robust yet flexible system that can adapt to changing field conditions and user workflows.

The MagArrow consists of an aerodynamic, light-weight shell with internal electronics including the MFAM™ magnetic sensors, GPS, and IMU.

The MFAM™, a two sensor module inside the MagArrow a groundbreaking magnetometer capable of highly precise measurements in an extremely lightweight and tiny package.

Survey plans are programmed into the UAV. Pre-programmed GPS waypoints carry the MagArrow in altitude stable survey lines. Once work is completed, data from the MagArrow can be wirelessly downloaded to a computer for further aeromagnetic data processing, which ultimately leads to ultra-high resolution aeromagnetic imaging.

Operating Principle: Laser pumped cesium vapor (Cs133 non-radioactive) total field scalar magnetometer

Operating Range: 20,000 to 100,000 nT

Gradient Tolerance: 10,000nT/m

Operating Zones: Configurable for operation anywhere in the world without dead zones

Dead Zone: Polar only, 60° inclusive angle

Noise/Sensitivity: 0.005nT/ Hz_{rms} typical (0.01nT/ Hz_{rms} guaranteed); (SX (export) version 0.02 nT/ Hz_{rms})

Sample Rate: 1000 Hz. synchronized to GPS 1PPS

Bandwidth: 400Hz.

Heading Error: ± 5 nT over entire 360° equatorial and polar spins typical

Output: WiFi data download over 2.4GHz WiFi access point

GPS: 3m 50% CEP

USB Port: Port for USB flash drive. Used for field upgrades

Data Logger: Built in Data Logger

Data Storage: 32 Gbyte Micro SD card, U3 speed class. Not field-accessible. Contact sales for higher capacities

Data Download: Over WiFi 2.4GHz using user-supplied browser-capable Android* device. 10 minutes of data requires 1 minute to download.

*note: this system is not compatible with iOS operating systems

IMU: Bosch BMI160 Accel/Gyro - 200 Hz sample rate. Insentek Compass - 100 Hz Sample rate

Total Weight: 1 kg without batteries

Length: 1 m

BATTERY

Battery Connection: 2x XT60 connectors for 206 type batteries
Battery Recommendations: Non-magnetic 1800 mAh or 2200 mAh lithium polymer, 3cell 11.1v. Hot swappable

ENVIRONMENTAL

Operating Temperature: -35°C to +45°C (-21°F to +113°F)
Humidity: Non-condensing

ACCESSORIES

Standard: Carrying case, AC power adapter, USB drive containing operation manual and software, JIS1 screwdriver and drill bit, suspension cords.

Table 4 – Technical specifications of the MagArrow UAV-Enabled Magnetometer.

The Matrice 350 RTK UAV that will be used for surveying with MagArrow is designed with a six-directional binocular vision system and an infrared sensing system for six-directional awareness, positioning, and obstacle-sensing capabilities, providing comprehensive protection during flight.

- Minimum Flight Time: 50 minutes (without payload).
- IP Rating: IP55.
- Maximum Transmission Range: Over 15 km.
- Maximum Payload: Over 2.5 kg.
- Positioning Accuracy with RTK:
  - Horizontal: 1 cm.
  - Vertical: 1.5 cm.
- Obstacle Detection System: Optical and infrared sensors in 6 directions.
- Integration System: Quick installation and integration of Laser, IMU-GNSS, and sensors.
- Batteries:
  - Intelligent, self-heating lithium polymer batteries with a capacity of over 5,500 mAh and a lifespan of at least 300 cycles.
  - 2 complete sets of batteries for the drone and 2 for the remote control.
- Charging Station: Capable of simultaneously charging at least 3 sets of batteries for the drone and 3 for the remote control.
- Spare Propellers: At least 2 complete sets.
- Dual Remote Controls: Full control with integrated screens of at least 7 inches.
- Storage and Transport: Wheeled case for storage and transportation.

Table 5 – Technical specifications of the Matrice 350 RTK UAV.

Figure 5 – Aeromagnetic drone for ultra-high resolution surveying.

2.3 Airborne Gravity Instrumentation

Within ITINERIS we are acquiring a state of the art iCORUS-02 (Inertial Measuring System for Navigation, Gravimetric Disturbances and Surveying Applications with Gyro Compassing Capability) strapdown gravity system.

This approach significantly improves upon standard airborne gravity both in terms of spatial resolution and accuracy of the gravity data that can be acquired. It also provides important added flexibility in airborne surveying. While standard marine gravity systems modified for airborne gravity applications typically require flying level, the strapdown system can cope with draped mode (terrain following) flying, which is often used for example in aeromagnetic and airborne radar surveys. Therefore there is an additional potential for multiple sensor integration and fields of application, while simultaneously collecting aerogravity data. Furthermore, the system recovers much faster than standard gravity after turns at the end of the survey line minimizing data loss.

The system provides gravimetric disturbances measurements, gyro compassing, inertial navigation, surveying, guidance and stabilization. It contains ring laser gyros and yields high accuracy, reliability, a flexible interface and easier integration and usage compared to standard airborne gravity meters. Advanced processing software is also being purchased to derive fully corrected Free-Air gravity anomaly from the raw strapdown gravity data outputs. The iCORUS-02 comes with an integrated sophisticated but easy to use temperature management system, which is particularly important to reduce biases and drift during airborne gravity surveying.

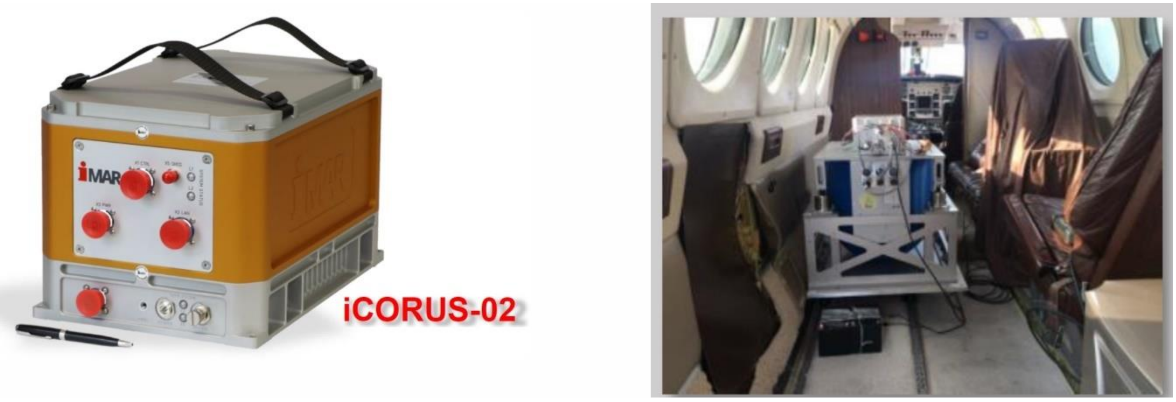

Figure 6 – Strapdown gravity system for higher resolution airborne gravity surveying.

Technical Data of iCORUS-02 (rms values)

Data Output:	Raw data for gravimetric disturb. postproc. Heading, Roll, Pitch, Angular Velocity, Velocity (Body and World), Position, Raw Data of INS / GNSS / VMS incl. time-stamp, internal status information		
Global Performance:	**Gravimetric Disturbances: (at 50 s resolution)**	**< 1.2 mGal**	under sufficient GNSS observations, reasonable motion conditions and with an appropriate post-processing (i.e. relative to an initial, externally surveyed, gravity reference point) (performance without linewise bias removal: < 2 mGal)
		0.8 – 1.0 mGal	typical performance under proper flight conditions
	True Heading:	< 0.02°	with at least single antenna GNSS (data fusion) and under sufficient motion dynamics (no dual antenna required)
		< 0.01°	post-proc with RTK corrections
		< 0.1° sec lat	gyro compassing (no GNSS support required)
	Position accuracy:	1…2 m	with GNSS, S/A off
		0.6 m	with SBAS
		0.02 m	with RTK corrections online or with RTK post-proc
		3 nm/hr [CEP]	free inertial navigation after sufficient GNSS aiding
	Velocity:	0.02 m/s	with GNSS; < 0.005 m/s with RTK post-proc
	Altitude:	< 1…4 m	with GNSS, S/A off
		0.06 m	with RTK corrections online or with RTK post-proc
	Roll/Pitch Accuracy:	0.01°	with GPS, S/A off; < 0.005° with RTK post-proc
Alignment Time:	< 2 min. GNSS cold start, < 1 min. GNSS warm start; < 30 sec with stored heading < 8 min. to achieve 0.1° sec lat, < 2 min. to achieve 0.5° sec lat (rms) with Gyro Compassing		

Inertial Sensor Performance:	Gyroscopes	Accelerometers
Range:	± 350 °/s (no angle limitation)	± 20 g
Linearity / Scalefactor:	< 15 ppm / < 10 ppm	< 100 ppm / < 30 µg/g²
Bias Stability (AV):	< 0.001 °/hr	< 1.0 µg | < 1.0 mGal
Resolution of Raw Data:	< 0.001 µrad / LSB	< 0.5 µg / LSB | < 0.5 mGal / LSB
Axis Misalignment:	< 30 µrad	< 50 µrad

GNSS Receiver (integrated):	all-frequencies / all-constellations GPS+GLONASS+GALILEO+BEIDOU, RTK/PPP, L-Band
Input Interfaces (options):	external GNSS receiver (standard: integrated GNSS receiver); event trigger (PPS / SYNC, RS422 level), odometer (opto-coupler input up to 32 V, A/B quadrature or counts & direction, RS422 level compliant)
Output Interfaces (options):	UART RS232/422, Ethernet TCP/IP / UDP, CAN, ARINC429, ARINC825, HDLC/SDLC, PPT (Pulse Per Time), PPS, SYNC; NTP on Ethernet as option; NTRIP caster as option; Pulse-per Distance
Data Output Rate:	1…400 Hz, internal data rate > 3 kHz
Data Latency and Jitter:	< 5.3 ms (sampling accuracy better 1 µs, time-stamped according to PPS; jitter < 1 ms)
Data storage:	up to 128 GByte on internal non-volatile memory (standard: 32 GByte)
Connectors:	MIL-C-38999 Series III for signals and power, TNC for antenna
Magnetic. insensitivity:	< 500 µTesla (5 Gauss) for operation within spec.
MTBF / MTTR:	> 50,000 hrs (estimated for surveying applications) / < 30 minutes
Shock, Vibration, Altitude:	6 g / 20 ms operational and 40 g / 15 ms non-operational; 60'000 ft 6.3 g rms (operating); 60,000 ft
Qualification:	MIL-STD-810G, MIL-STD-461G, MIL-STD-704F, DO160G; 8...100%; IP67
Temperature:	-30...+45°C operating (case), if environment. temp.change < ±15 K during mission -30...+65°C storage
Power:	iCORUS-02: < 250 W; 16...34 V DC; iCORUS-02-P: < 25 W; 16…34 V DC Power interruption hold up time according to DO160
Weight / Size:	iCORUS-02: approx. 18.5 kg / 260 x 240 x 380 mm³ (WxHxL), w/o connectors; iCORUS-02-P: approx. 8 kg / 187 x 130 x 330 mm³ (WxHxL), w/o connectors
Installation:	Installation in all arbitrary orientations allowed
Software:	iXCOM-CMD GUI software under MS Windows and Linux available; integrated real-time Kalman filter (42+ states); iXCOM communication protocol iPosCAL-GRAV: iMAR's advanced **gravimetry post-processing software**

Table 6 – Technical specifications of iMAR's iCORUS-02 strapdown gravity system.

2.4 Ground Penetrating Radar Drone

We are acquiring a GPR-drone integrated system to be mounted on the bottom of a commercially available drone between the landing gear. In terms of antenna we have purchased a multi frequency system with 200/400/800 MHz and an outstanding bandwidth (50-1400 MHz), which enable higher resolution and more flexible surveying than conventionally possible with single frequency systems.

Antenna type	Multi Frequency Antenna
Nominal frequencies	200/400/800 MHz
Operating bandwidth	50-1400 MHz
Applied voltage	200 V
Sample rate	100,000 samples/second
Scan rate	1-100 scans/s per channel @ 512 samples/scan
Sample output	16 bit digital raw data
CONTROL UNIT / CU	Selectable PC/PDA, Rugged

Table 7 – Technical specifications of Cobra CBD wireless Ground Penetrating Radar for drone deployment.

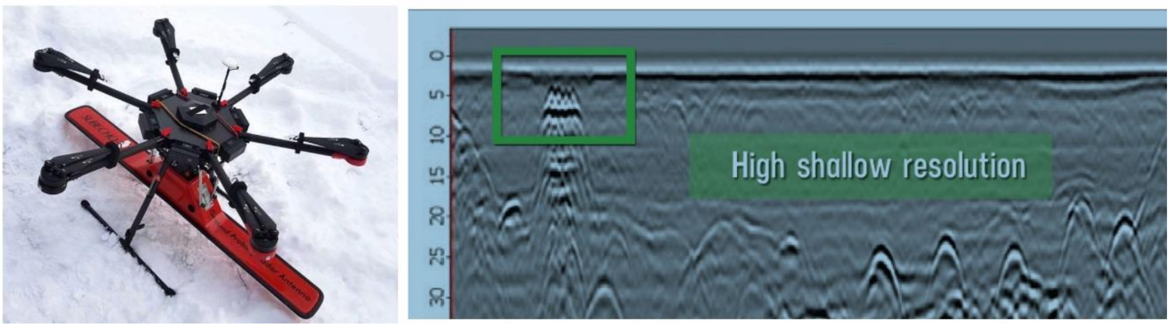

Figure 7 – Drone-based Ground Penetrating Radar with multi-frequency yielding very high resolution in shallow layers.