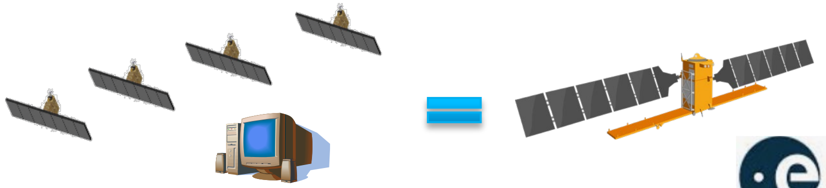
UAV-borne demonstrator of Multistatic SAR

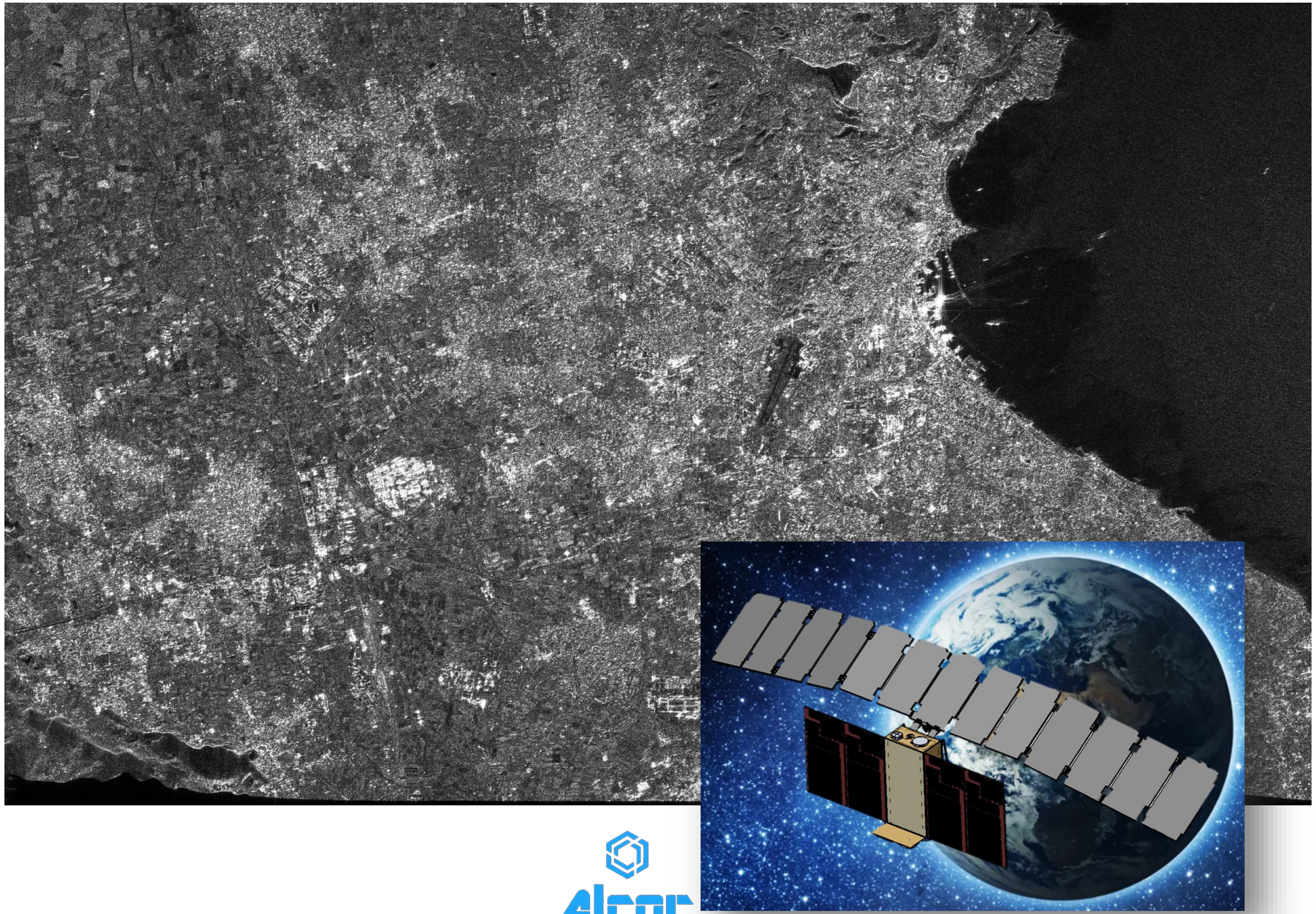
MULTISTATIC RADAR WORKSHOP 2025

Date: 17 July, 2025
Issue: 1.0
Author: Stefano Moro

Distributed SAR heritage



- **2018:** In the framework of the ESA study "Distributed SAR for Space 4.0", **ARESYS** identified solutions for distributed SAR Mission concepts, analyzed trade-offs and the corresponding predicted performance.
- **2021:** From this expertise, **ARESYS** started the X-band **MicroSAR** payload development with the project **SATURN** (**S**ynthetic **A**per**T**ure **R**adar C**U**besats Fo**R**mation Flyi**N**g) in the frame of ASI Alcor programme, aimed at becoming the first ever Space SAR MIMO mission.
- **2025:** The D3-SAR study aims at demonstrating the distributed SAR technology on drones.



Why Multistatic SAR from UAVs?

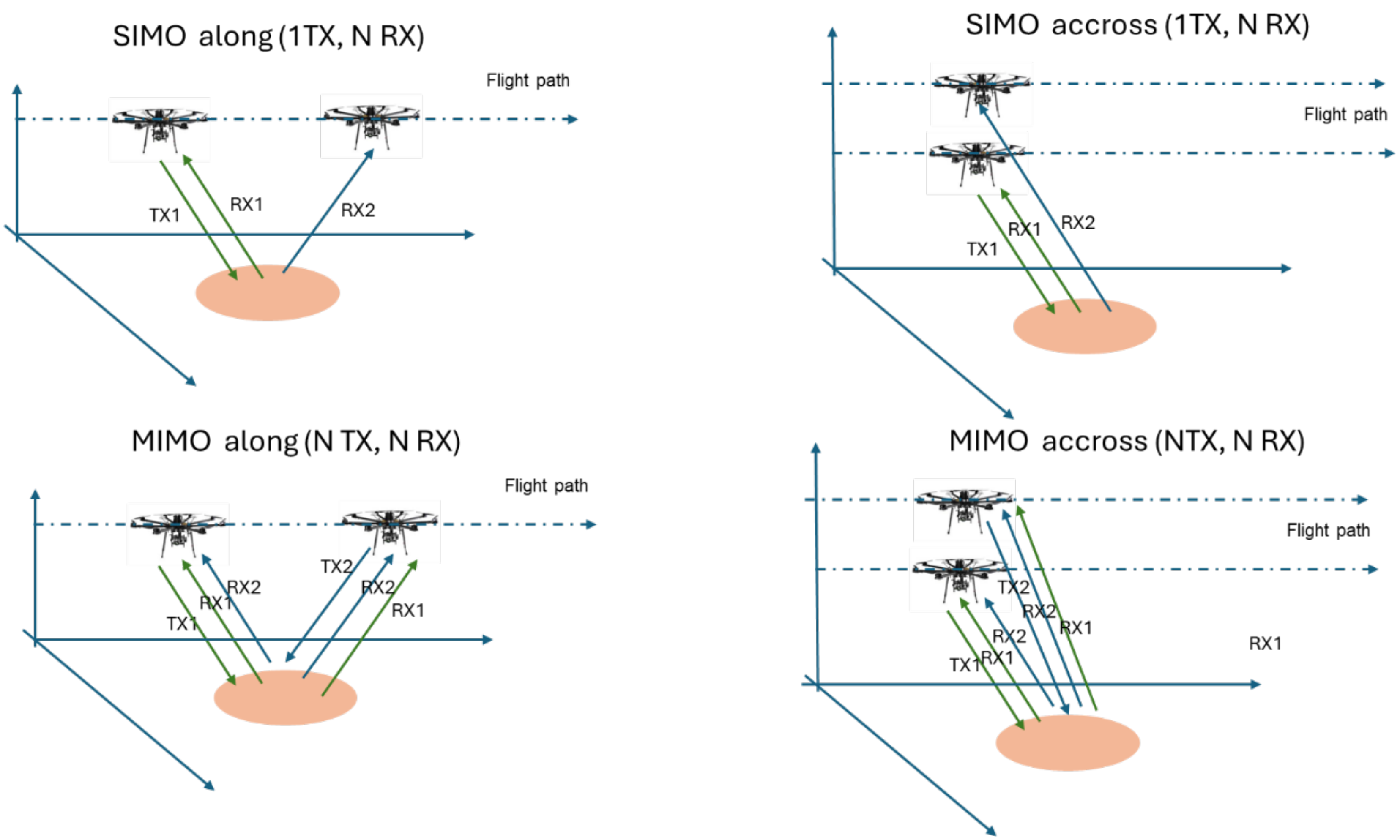
- **UAVs as a Scalable Testbed:**
  - Cost-effective and flexible platform for rapid prototyping
  - Real-world testing of synchronization, geometry, and system coordination
  - Ideal for early-stage validation of satellite-oriented concepts
- **Application Domains with High Impact Potential:**
  - **Forestry & Biomass:** Enhanced canopy penetration and 3D structure retrieval
  - **Soil Moisture & Hydrology:** Sensitivity to scattering mechanisms via spatial diversity
  - **Deformation Monitoring:** Complementary look angles improve spatiotemporal resolution
- **Accelerated Development Path:**

  UAV campaigns allow targeted, adaptable experimentation, bridging the gap between theory and satellite-scale implementation.

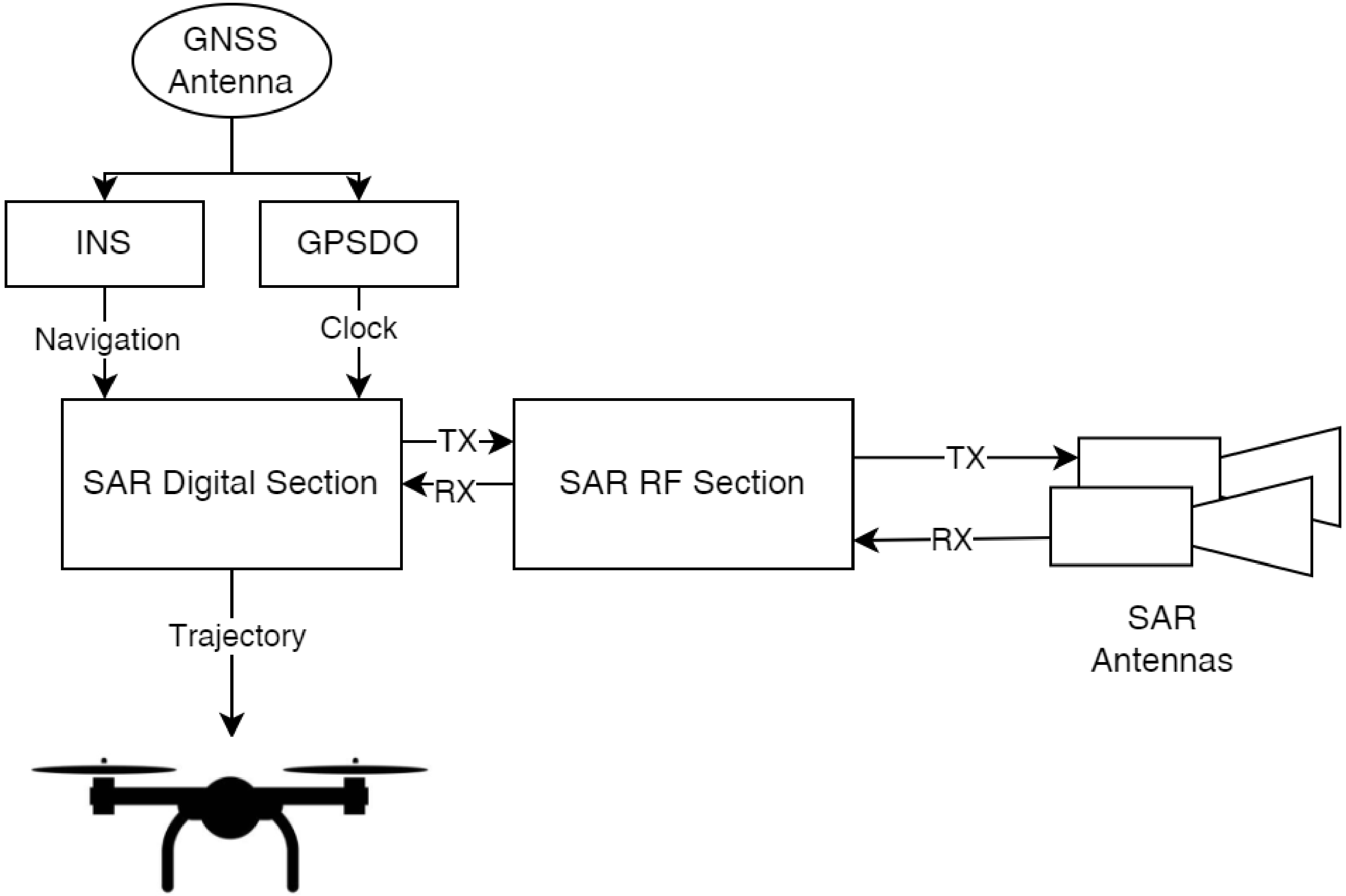
Multistatic SAR configuration

Application	Objective	Configuration	Ntx	Nrx
Across-track interferometry	Single-pass DEM generation using spatial baseline	SIMO across	1	2
Across-track tomography	Multi-channel single-pass tomography using virtual phase centers (MIMO concept)	MIMO across	3	3-5
Along-track interferometry	Ground Moving Target Indication (GMTI) via displaced phase centers	SIMO along	1	2
SATURN-Like swarm	MIMO SAR imaging enhancement and spatial diversity exploitation (as in ESA's SATURN mission concept)	MIMO along	3	3-5

Multistatic SAR configuration



System architecture



- Central frequency: 10GHz
- Bandwidth: 400MHz
- Payload Weight: 4.5Kg
- Modulation: FMCW
- Polarization: VV
- Acquisition Mode: Stripmap
- Focusing: TDBP

UAVs for SAR: Flexibility and Constraints

Why Multicopters?

- Enable **arbitrary flight paths** (straight, curved, hovering)
- Ideal for **along-/across-track** bistatic/multistatic configurations
- **Main constraint**: minimum drone spacing due to **safety protocols**

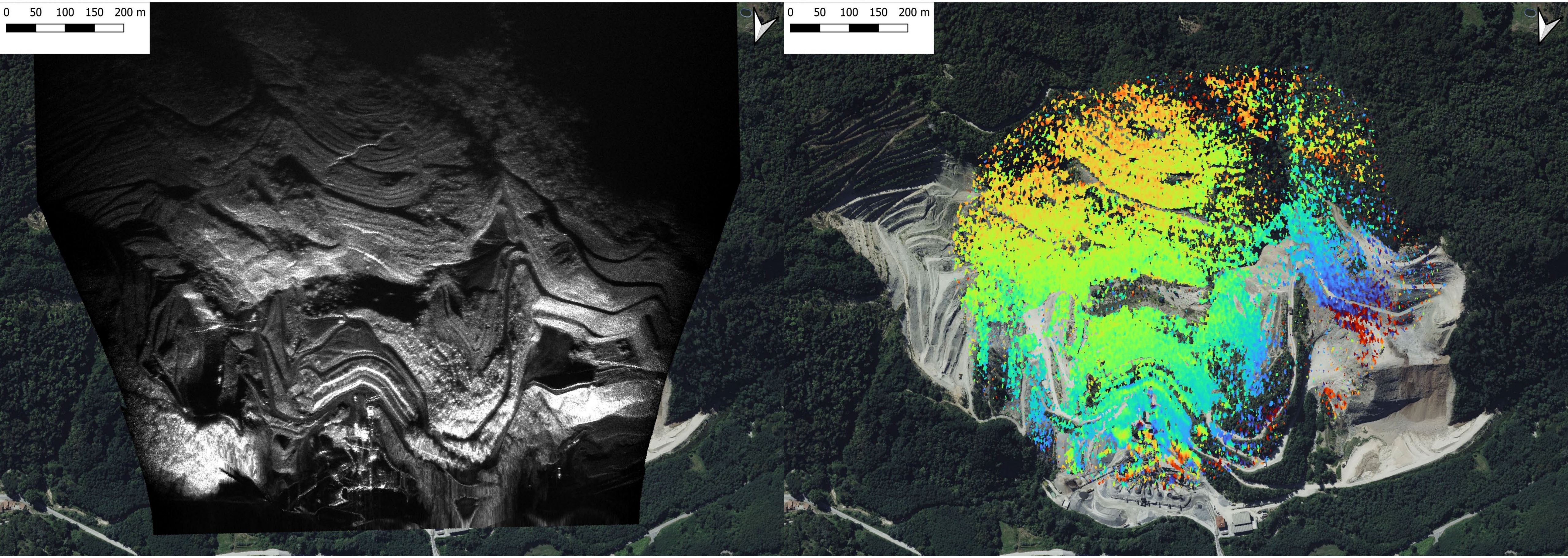
Key Differences vs. Satellites

- **Lower altitude** (e.g. 50–100 m) changes radar geometry
  - High incidence angle variation (10 deg to 70 deg)
  - Target scattering dinamics varying in the scene

Trajectory Accuracy: Critical for Focusing

- **Control accuracy**: ~1.5 m RMSE, influenced by wind & dynamics
- **Knowledge accuracy**: ~1 cm after flight with **RTK + INS fusion**
- **Deviations** lead to **defocusing**, mitigated by post processing refining methods

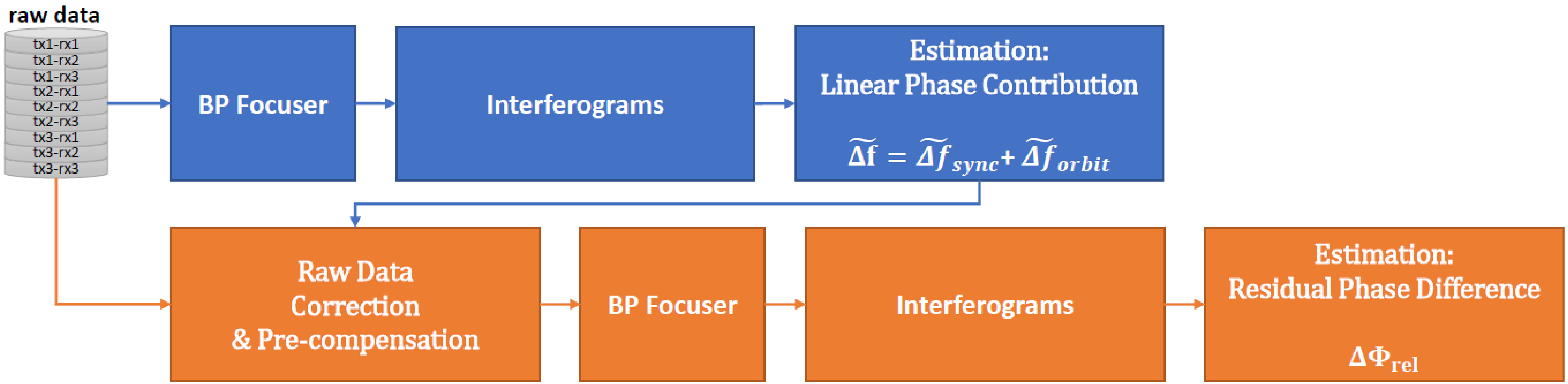
Monostatic Results



Time & Phase Synchronization Strategy

- **GPSDO-based Synchronization**
  - Each radar node is equipped with a GPS-disciplined oscillator (GPSDO)
  - Dual synchronization functions:
    - Radar 10 Mhz Clock
    - Acquisition Triggering
- **Post-processing Syncronization** :
  - Exploit inter-UAV direct link to further reduce residual time/phase drift
  - SATURN-like interferogram based correction

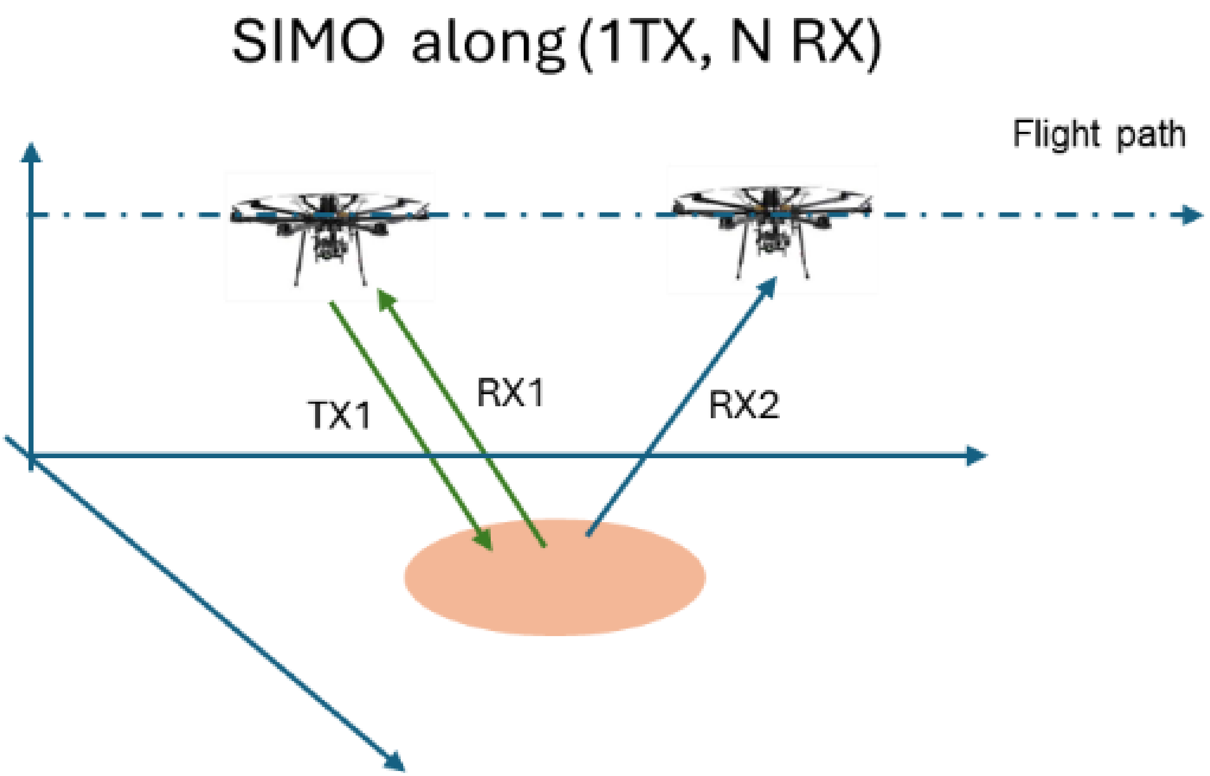
SATURN-like phase calibration

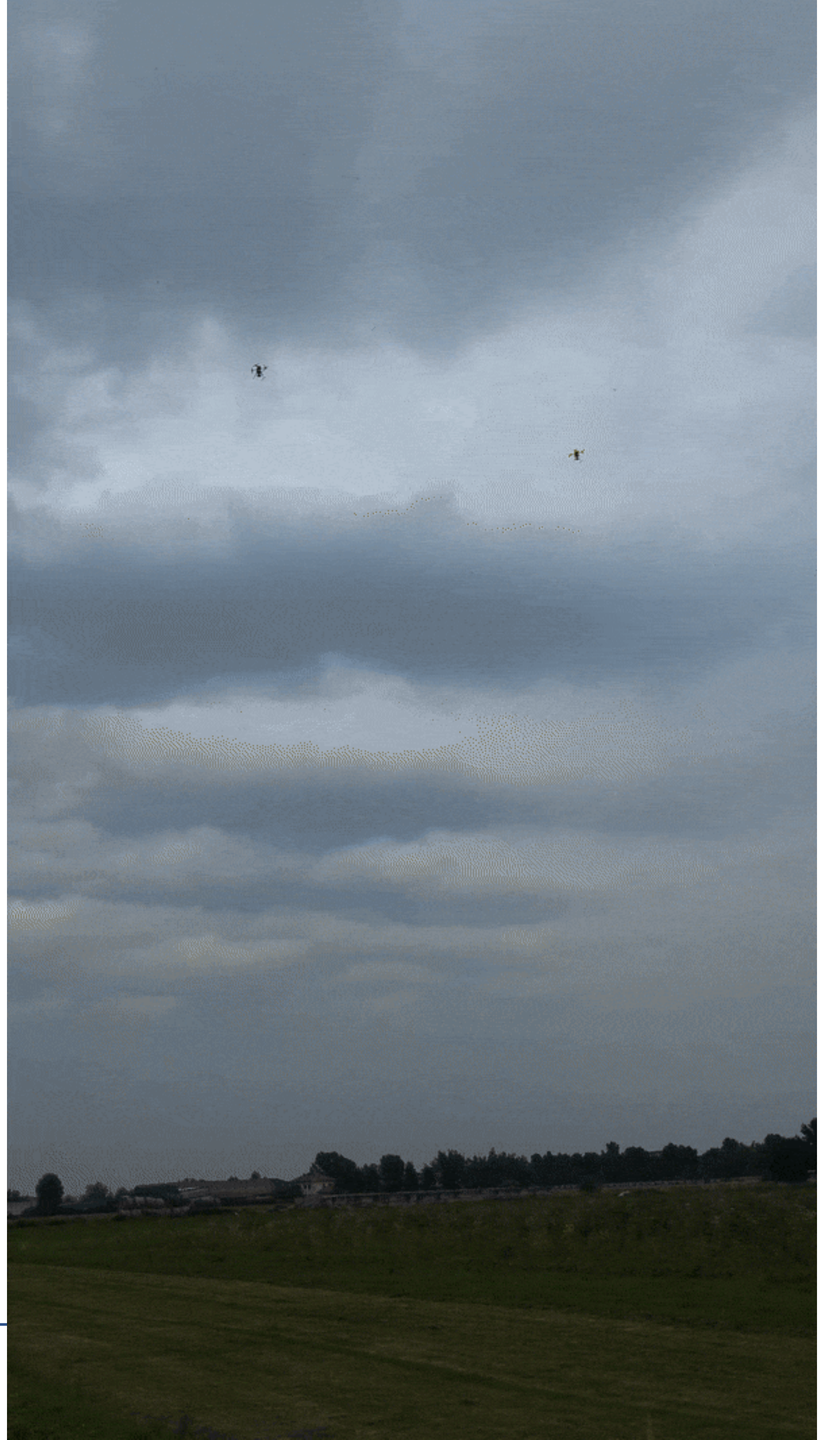


Preliminary Bistatic Test flight

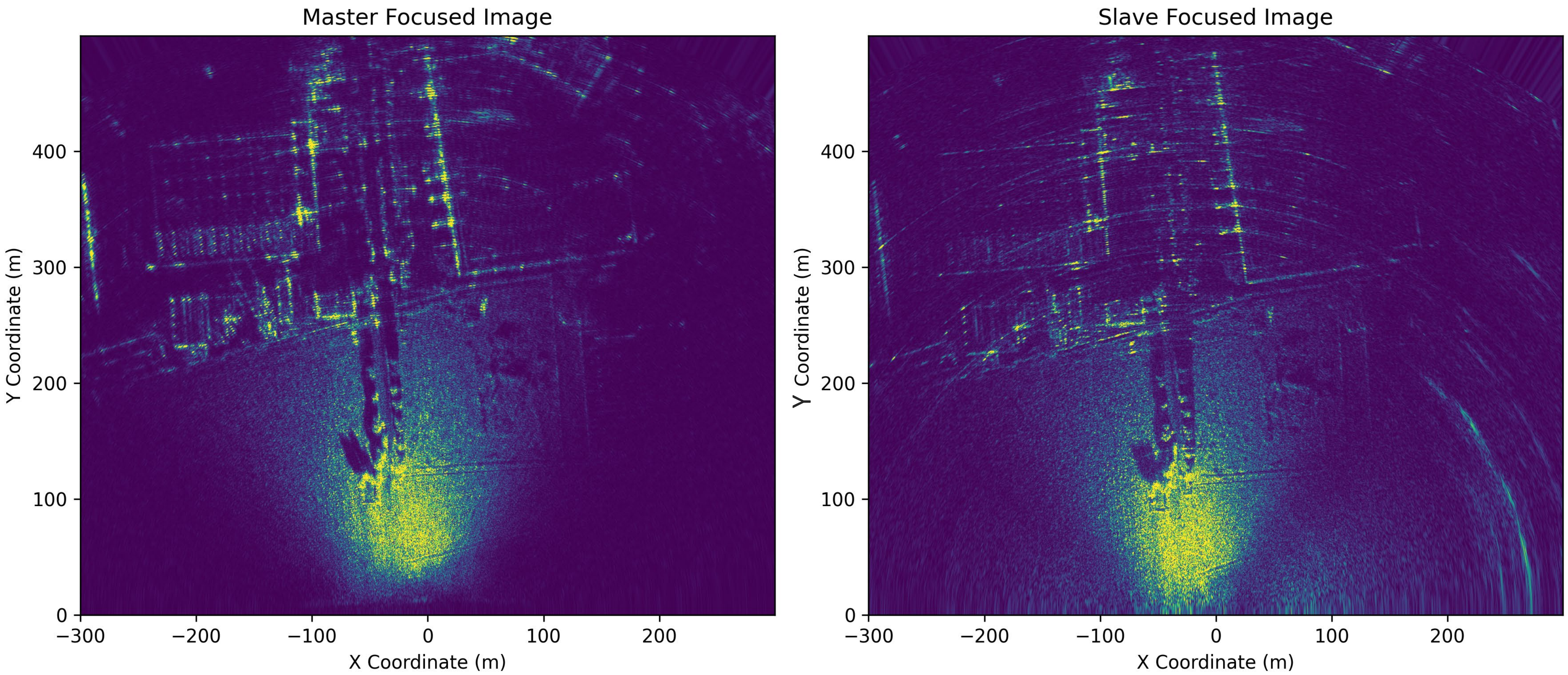
- **Location:** RC Airfield near Milan
- **Configuration:** SIMO (Single Input, Multiple Output)
  - **Primary platform:** Transmit and receive
  - **Secondary platform:** Receive only
- **Geometry:**
  - **Altitude:** 50 m AGL
  - **Along-track separation:** 25 m baseline
  - **Speed**: 2.5 m/s
- **Synchronization:** GNSS-disciplined oscillators (GPSDO) on both platforms
- **Objective:** Validate timing synchronization and bistatic signal reception in a real flight setup

Preliminary Bistatic test

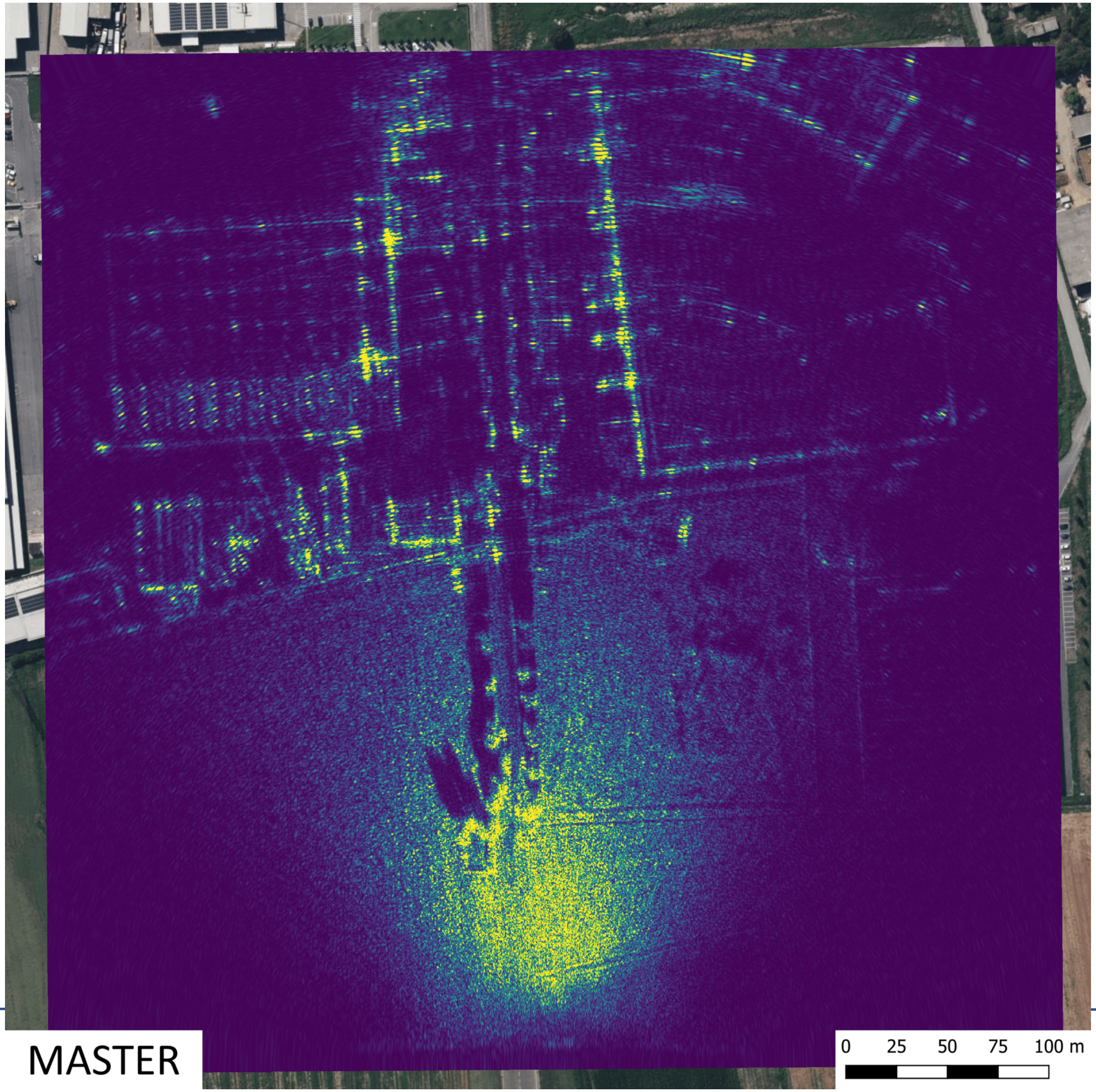




Preliminary Bistatic results



Preliminary Bistatic results



Challenges & Lessons Learned

- **Synchronization:**
  GPS-disciplined oscillators (GPSDOs) provided nominal clock stability ($\sim 10^{-11}$) allowing coherence summation of echoes.
- **Navigation Accuracy:**
  Navigation uncertainty, particularly on the secondary UAV, resulted in trajectory estimation errors that caused defocusing and limited image quality.
- **Low Altitude Effects:**
  The 50 m flight altitude led to high incidence angles, increasing ground shadowing and limiting visibility in the SAR footprint.

Next steps

- **Inter-Platform Link:**
  Investigate direct communication between platforms to enable synchronization corrections.
- **MIMO Bistatic Testing:**
  Conduct experiments with a Time Division Multiple Access (TDMA) scheme to validate MIMO bistatic SAR operation.
- **Scalability to Multiple Nodes:**
  Extend the architecture to support operations with 3+ synchronized platforms for fully multistatic configurations.