



PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Marianna Franzese

Cycle: XXXIX

Training and Research Activities Report

Academic year: 2024-25 - PhD Year: Second

Marianna Franzese

Tutor: Prof. Antonio De Maio

Antonio De Maio

Co-Tutor: Dr. Eng. Claudio De Luca (CNR-IREA)

Claudio De Luca

Date: October 31, 2025

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Author: Marianna Franzese

1. Information:

- **PhD student:** Marianna Franzese **PhD Cycle:** XXXIX
- **DR number:** 997194
- **Date of birth:** 14/02/1991
- **Master Science degree:** Telecommunication Engineering
- **University:** University of Naples “Federico II”
- **Scholarship type:** CNR Istituto per il Rilevamento Elettromagnetico dell’Ambiente (IREA)
- **Tutor:** Prof. Antonio De Maio
- **Co-tutor:** Dr. Eng. Claudio De Luca (CNR-IREA)

2. Study and training activities:

Activity	Type ¹	Hours	Credits	Dates	Organizer	Certificate ²
Cubes & Clouds	Course	20	4	18/12/2024	Dr. P.J. Zellner	Y
Presentation of the work “Addressing ionospheric impairments in the azimuth ground displacements retrieved by using SAOCOM-1 L-band SAR data” at the IEEE TechDefense 2024, Napoli, 11-13 Nov. 2024. Submission of the following abstract to the Living Planet Symposium 2025: “Enhancing the P-SBAS Processing Chain for L-Band DInSAR Time Series Retrieval: Insights from the SAOCOM-1 Constellation” (M. Franzese, C. De Luca, Y.Roa, M. Bonano, F.Casu, P. Euillades, L. Euillades, M. Manunta, M. Yasir, G. Onorato, P.	Research		4	01/11/2023 - 31/12/2023		

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<p>Striano L. Dini, D. Tapete and R. Lanari).</p> <p>Study of the following research papers:</p> <ul style="list-style-type: none">• Mapping high spatial resolution ionospheric total electron content by integrating Time Series InSAR with International Reference Ionosphere (Wenfei Mao, Peifeng Ma, Jun Tang);• Ionospheric Phase Delay Correction for Time Series Multiple-Aperture InSAR Constrained by Polynomial Deformation Model (Wenfei Mao, Xiaowen Wang, Guoxiang Liu, Peifeng Ma, Rui Zhang, Zhangfeng Ma, Jun Tang and Hui Liu);• Time Series InSAR Ionospheric Delay Estimation, Correction, and Ground Deformation Monitoring With Reformulating Range Split-Spectrum Interferometry (Wenfei Mao, Xiaowen Wang, Guoxiang Liu, Saied Pirasteh, Rui Zhang, Hui Liu, Yakun Xie, Wei Xiang, Zhangfeng Ma and Peifeng Ma).• Estimation and Compensation of Ionospheric Phase Delay for Multi-Aperture InSAR: An Azimuth Split-Spectrum Interferometry						
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Approach (Wenfei Mao, Xiaowen Wang, Guoxiang Liu, Rui Zhang, Yueling Shi and Saied Pirasteh). • Mapping the ionosphere with millions of phones (Jamie Smith, Anton Kast, Anton Geraschenko, Y. Jade Morton, Michael P. Brenner, Frank van Diggelen and Brian P. Williams).						
How to boost your PhD	Courses	25	5	08/01/2025 - 12/02/2025	Prof. Antigone Marino. University of Naples Federico II	Y
Lunar Laser Retroreflectors for ESA-ASI's Moonlight, Farside & South Pole	Seminar	1	0.2	16.01.2025	Prof. Giacomo Ascione, SSM Scientific Colloquia	Y
Optimisation-based Control of Flexible Resources in Sustainable Energy Networks	Seminar	1	0.2	05/02/2025	Prof. Luigi Glielmo	Y
Submission of the following paper to the Journal Remote Sensing of Environment: “Detailed Retrieval of the 3D Displacements, Fault Model, Shakemap and Strees Change of the Turkiye-Syria 6 February 2023 seismic events based on SAOCOM-1, ALOS-2, Sentinel-1 and Seismic Waveform Data	Research		10	01/01/2025 - 28/02/2025		

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<p>Analysis.” (N. Svigkas, P. Striano, S. Atzori, M. Bonano, N. Vavlas, C. Tolomei, A. Kiratzi, F. Casu, C. Bignami, C. De Luca, M. Polcari, M. Franzese, A. Antonioli, M. Manunta, F. Monterroso, Y. Roa, and R. Lanari).</p> <p>Submission of the following papers to the IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2025):</p> <ul style="list-style-type: none">• “Quantitative assessment of the retrieved SAOCOM-1 L-band DInSAR Time Series accuracy in volcanic and tectonic scenarios of the Italian territory” (Y. Roa, C. De Luca, M. Bonano, V. Bruno, F. Casu, P. De Martino, M. Franzese, S. Gandolfi, E. Giorgan, M. Manunta, M. Mattia, P. Noli, G. Onorato and R. Lanari).• “Evolution analysis of the Campi Flegrei caldera geodetic anomaly ground displacements through the exploitation of spaceborne multi-frequency DInSAR measurements” (F. Casu, M. Bonano, S. Buonanno, C. De Luca, P. De Martino, F. Di Traglia, M. Di Vito, M. Franzese, A. Fusco, F. Giudicepietro, R.						
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Lanari, G. Macedonio, M. Manunta, F. Monterroso, P. Noli, G. Onorato, Y. Roa, P. Striano, M. Yasir, G. Zeni and I. Zinno). Submission of the following abstract to the General Assembly 2025 of the European Geosciences Union (EGU): “Multidisciplinary exploitation of spaceborne DInSAR data for investigating volcanoes and seismic areas” (F. Casu, P. Berardino, M. Bonano, S. Buonanno, F. Casamento, F. Cotugno, C. De Luca, A. Di Vincenzo, C. Esposito, M. Franzese, A. Fusco, R. Lanari, M. Manunta, F. Monterroso, A. Natale, P. Noli, G. Onorato, S. Perna, Y. Roa, P. Striano, M. Yasir, G. Zeni and I. Zinno).						
Electronic Scan Antennas for Radar Signal Processing Applications	Courses	9	2	25/03/2025 - 11/04/2025	Prof. Massimo Rosamilia, Dr. Enzo Carpentieri. DIETI	Y
Dynamic Risk Assessment in Industrial Applications: Leveraging Bayesian Inference for Enhanced Decision-Making	Seminar	1	0.2	04/03/2025	Dr. Francesco Vitale	Y
5G & Digital	Seminar	4	0.8	14/03/2025	5G	Y

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Transformation: a view from an unconventional perspective (second edition)					Academy, lecturer Dr. Maurizio Irlando	
Submission of the following paper to the IEEE International Workshop on Metrology for Aerospace: "Radar Cross-Section Analysis of In-Flight UAVs in X- and L-Band" (M. Franzese, V. Carotenuto, F. Mattei, C. Conte, G. Rufino, D. Accardo, C. De Luca, P. Berardino, A. Di Vincenzo, C. Esposito, A. Natale, G. Palmese, S. Perna, R. Lanari and A. De Maio). Study of the following research papers: <ul style="list-style-type: none">• Radar detection performance via frequency agility using measured UAVs RCS data (M. Rosamilia, A. Aubry, A. Balleri, V. Carotenuto, and A. De Maio);• Radar target modeling using in-flight radar cross-section Measurements (B. Person);• Exploring the RCS of in-flight UAVs (F. Mattei, V. Carotenuto, C. Conte, G. Rufino, D. Accardo, P. Berardino, A. Di Vincenzo, C. Esposito, A. Natale, G. Palmese, S. Perna, R. Lanari and A. De Maio);	Research		5	01/03/2025 - 30/04/2025		

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<ul style="list-style-type: none"> Commercial drones radar cross section characterization at 24 GHz with a frequency modulated continuous wave Radar (R. Ardoino, S. Russo, R. Bagnato, N. Flagiello, L. Di Gregorio, and V. Rossi); On the capabilities of the Italian airborne FMCW axis InSAR system (C. Esposito, A. Natale, G. Palmese, P. Berardino, R. Lanari, and S. Perna). 						
<p>Submission of the following paper to the IEEE Sensors Journal: “In-Flight UAVs Polarimetric Radar Cross-Section Measurement and Statistical Analysis at X- and L-Bands” (M. Franzese, V. Carotenuto, F. Mattei, C. Conte, G. Rufino, D. Accardo, P. Berardino, A. Di Vincenzo, C. Esposito, A. Natale, G. Palmese, S. Perna, R. Lanari and A. De Maio).</p> <p>Study of the following research papers:</p> <ul style="list-style-type: none"> Operational Ionospheric Correction for SAOCOM Interferometry (N. Petrushevsky, F. Banda, A. Monti-Guarnieri, M. Thibeault, J.P. Cuenta Gonzalez, and D. 	Research		10	01/05/2025 - 30/06/2025		

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<p>Giudici);</p> <ul style="list-style-type: none">• Permanent scatterers in SAR interferometry (A. Ferretti, C. Prati, and F.Rocca);• BIOMASS Interferometric calibration processor design (F. Banda, S. Mancon, M. Mariotti D'Alessandro, S. Tebaldini, D. Giudici, M. Pinheiro, and K. Scipal);• Image coregistration in SAR interferometry (Z. Li and J Bethel);• Accuracy of Incoherent Speckle Tracking for Circular Gaussian Signals (F. De Zan) <p>Analysis of Global Ionospheric Maps (GIMs) for the estimation of ionospheric effects on SAR acquisitions, and development of filtering techniques for ionospheric correction on interferograms, aimed at improving the accuracy of deformation measurements.</p>						
Cooperative and Non-Cooperative Localization Systems	Courses	16	3	09/06/2025 - 25/06/2025	Prof. Massimo Rosamilia. DIETI	Y
Submission of the following papers to the XII° AIT International Conference (Smart Earth Observation for a Sustainable Future):	Research		7	01/07/2025 - 31/08/2025		

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<ul style="list-style-type: none">• “Generation and analysis of spaceborne DInSAR products to support Civil Protection activities in volcanic and seismic regions” (F. Monterroso, M. Bonano, S. Buonanno, F. Casamento, F. Cotugno, C. De Luca, M. Franzese, A. Fusco, M. Manunta, G. Onorato, Y. Roa, P. Striano, M. Yasir, G. Zeni, I. Zinno, R. Lanari and F. Casu).• “DInSAR time-series automatic generation of the Italian territory by exploiting Sentinel-1 SAR data archives through the P-SBAS approach” (P. Noli, M. Bonano, S. Buonanno, F. Casamento, F. Casu, F. Cotugno, C. De Luca, M. Franzese, A. Fusco, M. Manunta, F. Monterroso, G. Onorato, Y. Roa, P. Striano, M. Yasir, G. Zeni, I. Zinno and R. Lanari).• “Extensive Full Resolution P-SBAS analysis for monitoring critical displacements related to the built-up environment over the Italian territory” (P. Striano, M. Bonano, S. Buonanno, F. Casamento, F. Casu, F. Cotugno, C. De Luca, M. Franzese, A. Fusco, M. Manunta, F. Monterroso, P. Noli, G. Onorato, Y. Roa, M.						
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<p>Yasir, G. Zeni, I. Zinno and R. Lanari).</p> <p>Study of the following research papers:</p> <ul style="list-style-type: none">• Techniques and tools for estimating ionospheric effects in interferometric and polarimetric SAR data (P. Rosen, M. Lavallo, X. Pi, S. Buckley, W. Szeliga, H. Zebker and E. Gurrola);• Correction of Ionospheric Phase in SAR Interferometry Considering Wavenumber Shift (G. Li, Z. Hu, Y. Wang, Z. Dong, and H. Li). <p>Study of the ISCE2 software and its application to the estimation of ionospheric effects on SAR acquisitions, aimed at obtaining reference results for the comparison and validation of the developed filtering techniques for ionospheric correction and the consequent improvement of deformation estimation.</p>						
<p>Estimations of Unimodular Signal Waveform and Uncertain Receive Signal Steering Vector for Robust Optimal Receive Beamforming Design</p>	<p>Seminar</p>	<p>1</p>	<p>0.2</p>	<p>02/10/2025</p>	<p>Prof. Massimo Rosamilia</p>	<p>Y</p>

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Assessing 5G Health Implications: In Vitro Studies at 26.5 GHz in the Framework of RESTART-6GWINET Project	Seminar	2	0.4	09/10/2025	Dott.ssa Valentina Peluso	Y
A Gentle and Incomplete Introduction to Bilevel Optimization	Seminar	1	0.2	15/10/2025	Prof. M. Bocci, Prof. C. Sterle, Prof. A. Masone	Y
Optimization in Transportation and Logistics	Seminar	1	0.2	16/10/2025	Prof. M. Bocci, Prof. C. Sterle, Prof. A. Masone	Y
Local Explainability in Machine Learning: A collective framework	Seminar	1	0.2	16/10/2025	Prof. M. Bocci, Prof. C. Sterle, Prof. A. Masone	Y
Exact and ML-guided Matheuristic approaches for a Truck-and-Drone delivery problem	Seminar	1	0.2	17/10/2025	Prof. M. Bocci, Prof. C. Sterle, Prof. A. Masone	Y
Guardians or Threats? AI at the Frontlines of Cybersecurity	Seminar	4	0.8	17/10/2025	Prof.ssa Antonia Tulino	Y
Boosting Your Citations: Maximizing the Impact of Your Publications	Seminar	2	0.4	21/10/2025	Dr. Zachary M. Wilmot, Dr. Rong Han	Y
AI Powered User Interface Design	Seminar	4	0.8	24/10/2025	Prof.ssa Antonia Tulino	Y
Velocizzazione di SAR focusing nel dominio del tempo (TD)	Seminar	2	0.4	28/10/2025	Dr. Jorge Euillades	Y
Quality of services	Seminar	4	0.8	28/10/2025	Prof.ssa Antonia Tulino	Y
Study of the following research papers: • Estimation of Ionosphere Compensated Azimuth	Research		9	01/09/2025 - 31/10/2025		

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<p>Ground Motion with Sentinel-1 (G.Gomba);</p> <ul style="list-style-type: none">• Reformulating the Split-Spectrum Method to Facilitate the Estimation and Compensation of the Ionospheric Phase in SAR Interferograms (U. Wegmüller, C. Werner, O. Frey, C. Magnard and, T. Strozzi);• Estimation and Compensation of the Ionospheric Path Delay Phase in PALSAR-3 and NISAR-L Interferograms (U. Wegmüller, C. Werner, O. Frey and, C. Magnard);• Multi-layer ionosphere correction in low-frequency interferometric SAR: modeling, inversion, and application to BIOMASS (S. Tebaldini, F. Salvaterra, F. Banda and, M. Pinheiro);• Recovering Time and Space Varying Phase Screens through SAR Multi-Squint Differential Interferometry (S. Tebaldini, A. Monti Guarnieri, F. Rocca). <p>Development and implementation of an enhanced Range Split-Spectrum filtering approach for the estimation and mitigation of ionospheric phase</p>						
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distortions on L-band SAR interferograms, followed by validation analyses over different test sites using SAOCOM-1 data and comparison with the results obtained through ISCE2 processing						
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- 1) Courses, Seminar, Doctoral School, Research, Tutorship
- 2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	4	0	4	0	8
Bimonth 2	5	0.4	10	0	15.4
Bimonth 3	2	1	5	0	8
Bimonth 4	0	0	10	0	10
Bimonth 5	3	0	7	0	10
Bimonth 6	0	4.6	9	0	13.6
Total	14	6	45	0	65
Expected	30 - 70	10 - 30	80 - 140	0 - 4.8	

3. Research activity:

MAIN TOPIC: Development of Algorithms to Process L-Band SAR Data: Focusing on the Detection and Mitigation of Ionospheric Disturbances through an Enhanced Range Split-Spectrum Approach

The research activity of this PhD focuses on the detection and mitigation of ionospheric impairments affecting L-band Synthetic Aperture Radar (SAR) data, a topic of increasing scientific and technological relevance. Indeed, several international space agencies have recently launched or planned L-band SAR missions, including SAOCOM-1 (CONAE), PALSAR-2 and PALSAR-3 (JAXA), NISAR (NASA-ISRO), and ROSE-L (ESA). These systems play a crucial role in monitoring ground deformations and geophysical phenomena, thanks to the deeper penetration capability of L-band signals and their higher temporal coherence compared with shorter wavelengths, such as those in the C- and X-bands. However, the use of L-band sensors also introduces one of the most critical issues associated with this frequency range, namely the presence of ionospheric effects, which can significantly impact both the phase and amplitude of the acquired signals, thus affecting the quality of interferometric products and, consequently, displacement measurements.

During the first year of the PhD, an extensive review of the state of the art has been conducted, together with experimental and methodological analyses aimed at characterizing the ionospheric disturbances affecting L-band SAR data. In particular, it has been observed that ionospheric perturbations can induce local sub-pixel azimuth shifts in SAR images, influencing the co-registration process and consequently the accuracy of ground displacement estimation. These effects appear in deformation maps generated through Multi-Aperture Interferometry (MAI) or Pixel Offset Tracking (POT) techniques as the well-known “azimuth

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streaks”, i.e., linear patterns aligned with the flight direction that reflect azimuthal ionospheric gradients. This activity provided insights into the dependence of azimuth distortions on angular diversity, offering a conceptual and experimental basis for the subsequent development of correction methodologies.

Building on the results achieved during the first year, the second-year research activity focused on the development of an enhanced Range Split-Spectrum (RSS) approach. The proposed method relies on the principle of the conventional RSS technique, which exploits the dispersive nature of the ionosphere to separate it from the non-dispersive phase components, namely those related to topography, ground deformation, and atmospheric contributions mainly due to the troposphere. The RSS method involves the division of the radar signal spectrum into three adjacent sub-bands, where the sub-bands relevant the sides of the spectrum (labeled as low and high sub-bands) are then used to generate the corresponding interferograms, whose difference, properly weighted with specific coefficients depending on the central frequencies of the generated sub-bands, allows the estimation of the ionospheric phase component.

Despite its wide adoption and proven effectiveness in mitigating ionospheric effects, the RSS approach presents several operational limitations that can affect the accuracy of the phase artefacts depending on the propagation through ionosphere. A major issue is the need for accurate image co-registration, as it is essential to compensate for ionospheric azimuth shifts and to prevent possible loss of coherence and biased phase estimates. Moreover, the conventional RSS method requires the unwrapping of the low and high sub-bands interferograms, which must be performed with particular care, since the resulting phases are subsequently multiplied by a non-integer factor that jointly arises the ionospheric signal and amplified both the noise and the phase unwrapping errors. The use of the phase unwrapping procedure is essential to correctly perform the non-integer factor multiplication since the interferometric phase is wrapped modulo 2π , non-integer rescaling can compromise phase continuity and introduce artificial discontinuities. The amplification of interferometric noise occurring during the rescaling process makes the ionospheric estimate highly sensitive to decorrelation effects. This issue highlights the need for robust filtering strategies capable of suppressing noise while preserving the ionospheric signal. The final accuracy of the ionospheric estimation therefore depends on several factors, including the available bandwidth, the interferogram coherence, and the robustness of the applied filtering and processing strategies.

Despite these challenges, the RSS method remains the most widely used and effective approach for ionospheric correction in Differential Interferometric Synthetic Aperture Radar (DInSAR), providing the conceptual and methodological foundation for the research activity carried out during this second year of the PhD, aimed at enhancing its performance under challenging ionospheric conditions.

METHODOLOGY

The proposed methodology addresses the main limitations of the standard RSS method by introducing an enhanced approach that improves the estimation of the ionospheric component through an iterative procedure based on a spectral filtering strategy, which effectively reduces the typical noise amplification affecting the conventional method.

The processing workflow begins with the accurate co-registration of SAR images, performed using the azimuth shifts estimated through the POT technique. This operation is essential to compensate for the misregistration errors caused by ionospheric variations along the flight direction, which would otherwise lead to coherence loss.

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Subsequently, the radar signal spectrum is divided to apply the RSS method and estimate the ionospheric component as the product between the phase difference of the interferograms generated from the low and high sub-bands and an ionospheric extraction factor that depends on their central wavelengths. In its conventional implementation, the spectrum is divided into three equal sub-bands, and the resulting extraction factor assumes a large non-integer value, leading to a significant amplification of noise in the estimated phase. To overcome this limitation, the proposed method introduces an optimized selection of the sub-band central wavelengths, designed to obtain an integer-valued scaling factor and to factorize it into small prime numbers. This strategy enables an iterative processing in the wrapped phase domain, reducing the need for multiple phase unwrapping operations and effectively mitigating noise amplification during the estimation process.

The optimal selection of the sub-band central wavelengths is performed by introducing a guard band around the carrier wavelength to ensure adequate spectral separation between the low and high sub-bands. Additional lateral guard bands are applied at the spectrum edges to preserve a sufficient effective bandwidth for the resulting sub-bands. This configuration defines a set of admissible wavelength ranges within which the possible low and high central wavelengths can vary. Among all admissible combinations, only those that yield an integer-valued ionospheric extraction factor when substituted into its expression are retained. Finally, among the obtained integer factors, the selected wavelengths pair combination is the one that maximizes the number of divisors of the ionospheric extraction factor and, in case of equal divisor count, the implemented procedure will select the solution with the largest overall sub-band bandwidth. The core of the proposed methodology lies in the iterative application of the divisors of the integer ionospheric extraction factor, combined with spectral filtering at each processing step. This approach systematically limits noise amplification by progressively attenuating the high-frequency components that do not belong to the ionospheric contribution, which is characterized by slowly varying spatial patterns. To implement this strategy, the divisors are applied in ascending order, thereby reducing noise accumulation during the early iterations, when the signal-to-noise ratio (SNR) is higher, and ensuring that spectral filtering can be applied more effectively without compromising the accuracy of the ionospheric phase estimation. An important additional feature of the proposed methodology is that the use of integer factors reduces the number of phase unwrapping operations. Indeed, while in the conventional method it is necessary to unwrap both interferometric phases corresponding to the low and high sub-bands, in the proposed approach the unwrapping operation is performed only on the low-band interferogram. This makes the approach computationally lighter and reduces the likelihood of introducing undesired phase discontinuities during the estimation of the ionospheric component.

RESULTS

The proposed enhanced Range Split-Spectrum methodology has been applied to multiple SAOCOM-1 interferometric pairs acquired over different geographical regions to evaluate its performance and robustness under varying ionospheric conditions. The analysis has been aimed at assessing the method's capability to effectively isolate and mitigate ionospheric phase distortions, while preserving the non-dispersive component related to ground deformation.

In order to validate the proposed approach, a comparison has been carried out with the standard RSS implementation available in the ISCE (InSAR Scientific Computing Environment) software, a widely used open-source framework for SAR and InSAR data processing developed by the Jet Propulsion Laboratory (JPL). The results have shown that the proposed methodology provides more accurate estimates of the

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ionospheric component, particularly in low-coherence areas, where the conventional ISCE filtering implementation tends to generate phase artefact caused by the high noise levels. In these regions, the integer factorization and the iterative filtering steps of the proposed method have enabled a more stable reconstruction of the ionospheric component. Overall, the obtained results have confirmed the robustness and effectiveness of the enhanced RSS technique, highlighting its potential for operational use in L-band interferometric applications and for the generation of high-quality deformation maps in ionospherically active regions.

Future work will focus on implementing the proposed approach within DInSAR processing chains, with the aim of analyzing long temporal series of SAR images and improving the accuracy of deformation time-series in ionospherically disturbed areas. Another future development will involve the application of the optimal sub-band selection strategy to NISAR data, which already includes an operational Split-Spectrum module at system level, in order to evaluate whether an optimized selection of sub-bands can further enhance ionospheric correction performance and improve product quality.

TOPIC: **Statistical Characterization of In-Flight UAVs Radar Cross Section at X- and L-Bands**

During this year, a significant part of the research activity has been devoted to the experimental and statistical study of the Radar Cross Section (RCS) of unmanned aerial vehicles (UAVs) in flight, with the aim of showing and quantifying how the statistical behavior of the RCS varies with radar frequency, polarization configuration, and drone type.

This activity has led to the publication in the IEEE Sensors Journal of the paper “In-Flight UAVs Polarimetric Radar Cross-Section Measurement and Statistical Analysis at X- and L-Bands”, which represents an original contribution to the study of the electromagnetic scattering mechanisms of UAVs. The work has proposed a coordinated experimental design that integrates radar hardware, UAV mission planning, data acquisition, signal processing, and statistical analysis within a consistent framework. The paper also introduces a general and reusable RCS estimation procedure, independent of the specific UAV model under test, and provides experimental evidence that polarization diversity is a key factor in enhancing radar-based UAV discrimination and classification capabilities.

This research activity has originated from the growing need to develop realistic models of UAV radar signatures, which are essential for the design of advanced algorithms for detection, tracking, and classification in real surveillance scenarios. In recent years, the use of UAVs has rapidly expanded in both civil and military domains, leading to the definition of new regulations for the safe management of air traffic and for Beyond Visual Line of Sight (BVLOS) operations. In this context, the ability to reliably detect and track UAVs has become a crucial requirement for airspace security. However, small UAVs exhibit weak and highly variable radar signatures, and their electromagnetic behavior cannot be accurately described by the traditional Swerling models commonly used for RCS modeling. To address these limitations, the activity has been developed through an innovative approach based on in-flight measurements and multi-band, multi-polarization statistical analysis, with the goal of achieving a more comprehensive representation of the electromagnetic scattering mechanisms of UAVs and improving the understanding of their radar signatures under realistic operating conditions.

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METHODOLOGY

In the context of this research activity, the experimental phase was carried out using the MIPS (Multiband Interferometric and Polarimetric Synthetic Aperture Radar) system, a Frequency Modulated Continuous-Wave (FMCW) radar primarily designed for airborne SAR remote sensing applications. In this study, two operational modes were employed, namely the X-band single-pass interferometric configuration and the L-band fully polarimetric configuration, which allowed the collection of the four polarization channels (HH, HV, VH, and VV). The measurement campaign was conducted in a designated drone-flying area located in Castel Volturno (Province of Caserta, southern Italy), managed by the University of Naples Federico II. The experimental test campaign involved two Commercial-Off-The-Shelf (COTS) UAVs, namely the DJI Matrice 300 and the DJI Mavic 2 Enterprise Dual. The rationale behind this choice was to select two UAV platforms with different Maximum Take-Off Mass (MTOM) values, representative of distinct operational categories that could be employed for advanced operations within the U-space environment. All flights were carried out in automatic mode, by setting pre-defined waypoints with three-dimensional coordinates (latitude, longitude, and altitude) through the mission-management systems provided by the drone manufacturers. This configuration ensured repeatable trajectories and stable operating conditions, which were essential to guarantee the accuracy of the RCS measurements and to synchronize radar acquisitions with UAV telemetry data.

Based on the acquired radar data, the estimation of the RCS of the UAVs has been performed. It is important to underline that the procedure adopted for this estimation is independent of the specific UAV model under test. In more detail, the estimation method relies on inverting the radar range equation in order to retrieve the RCS from directly measurable quantities, namely the received power and the slant-range distance of the target. The actual range of the drones can be estimated as the locations on the range axis corresponding to the amplitude peaks of the range profile. The contributions of the UAVs to the power of the received signal, on the other hand, are proportional to the square of the amplitude peaks in the range profile, as each squared peak value represents the power return from the corresponding range. Once the RCS values had been estimated, a statistical analysis was performed to characterize the fluctuation behavior of the radar backscatter from the UAVs. The Empirical Cumulative Distribution Function (ECDF) of the estimated RCS values is used to assess the statistical behavior of each UAV. In addition, complementary statistical metrics are employed to quantify the dispersion of the RCS fluctuations under different operating conditions, including the standard deviation, interquartile range, full range, and box-and-whisker plots. A quantitative evaluation is then performed using the Cramér–von Mises (CVM) distance, with the aim of identifying the theoretical models that best fit the experimental data for each considered radar band and polarization configuration. Specifically, the CVM distance has been evaluated using the Exponential, Gamma, Log-Normal, Weibull, and Generalized Pareto distributions as candidate models.

RESULTS

The results of the statistical characterization of the RCS, obtained from the experimental campaign, show that both the UAV type and the radar operating conditions, namely the frequency band and the polarization configuration, significantly influence the statistical behavior of the RCS. Specifically, the DJI Mavic 2 Enterprise Dual, characterized by a smaller and more compact structure, exhibits more stable and bounded RCS fluctuations. In contrast, the DJI Matrice 300 shows stronger variability, mainly due to its larger size and more complex design. A significant outcome of the study is that polarization diversity improves radar

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discrimination and classification capabilities, providing deeper insight into the electromagnetic scattering mechanisms of UAVs under different operating conditions. In particular, for a given UAV, the best-fitting RCS distribution changes between the X- and L-band, and, in the case of L-band, also across the different polarimetric channels.

Future work could extend this analysis by including additional UAV platforms and more dynamic flight conditions, such as the presence of multiple drones operating simultaneously (e.g., drone swarms). Furthermore, future developments could investigate the impact of flight dynamics and propeller motion on the temporal variability of the RCS.

4. Research products:

- **M. Franzese**, V. Carotenuto, F. Mattei, C. Conte, G. Rufino, D. Accardo, P. Berardino, A. Di Vincenzo, C. Esposito, A. Natale, G. Palmese, S. Perna, R. Lanari and A. De Maio “In-Flight UAVs Polarimetric Radar Cross-Section Measurement and Statistical Analysis at X- and L-Bands”, *IEEE Sensors Journal*.
- **M. Franzese**, A. De Maio, R. Lanari, A. Aubry, P. Noli, G. Onorato, Y. Roa, P. Striano, and C. De Luca “Addressing ionospheric impairments in the azimuth ground displacements retrieved by using SAOCOM-1 L-band SAR data”, *IEEE TechDefense 2024*
- **M. Franzese**, V. Carotenuto, F. Mattei, C. Conte, G. Rufino, D. Accardo, C. De Luca, P. Berardino, A. Di Vincenzo, C. Esposito, A. Natale, G. Palmese, S. Perna, R. Lanari and A. De Maio “Radar Cross-Section Analysis of In-Flight UAVs in X- and L-Band”, *IEEE International Workshop on Metrology for Aereospace 2025*.
- **M. Franzese**, C. De Luca, Y. Roa, M. Bonano, F. Casu, P. Euillades, L. Euillades, M. Manunta, M. Yasir, G. Onorato, P. Striano, L. Dini, D. Tapete and R. Lanari “Enhancing the P-SBAS Processing Chain for L-Band DInSAR Time Series Retrieval: Insights from the SAOCOM-1 Constellation”, *Living Planet Symposium 2025*.
- Y. Roa, C. De Luca, M. Bonano, V. Bruno, F. Casu, P. De Martino, **M. Franzese**, S. Gandolfi, E. Giorgan, M. Manunta, M. Mattia, P. Noli, G. Onorato and R. Lanari “Quantitative assessment of the retrieved SAOCOM-1 L-band DInSAR Time Series accuracy in volcanic and tectonic scenarios of the Italian territory”, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 2025*.
- F. Casu, M. Bonano, S. Buonanno, C. De Luca, P. De Martino, F. Di Traglia, M. Di Vito, **M. Franzese**, A. Fusco, F. Giudicepietro, R. Lanari, G. Macedonio, M. Manunta, F. Monterroso, P. Noli, G. Onorato, Y. Roa, P. Striano, M. Yasir, G. Zeni and I. Zinno “Evolution analysis of the Campi Flegrei caldera geodetic anomaly ground displacements through the exploitation of spaceborne multi-frequency DInSAR measurements”, *IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 2025*.
- F. Casu, P. Berardino, M. Bonano, S. Buonanno, F. Casamento, F. Cotugno, C. De Luca, A. Di Vincenzo, C. Esposito, **M. Franzese**, A. Fusco, R. Lanari, M. Manunta, F. Monterroso, A. Natale, P. Noli, G. Onorato, S. Perna, Y. Roa, P. Striano, M. Yasir, G. Zeni and I. Zinno “Multidisciplinary exploitation of spaceborne DInSAR data for investigating volcanoes and seismic areas”, *EGU General Assembly 2025*.

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- F. Monterroso, M. Bonano, S. Buonanno, F. Casamento, F. Cotugno, C. De Luca, **M. Franzese**, A. Fusco, M. Manunta, G. Onorato, Y. Roa, P. Striano, M. Yasir, G. Zeni, I. Zinno, R. Lanari and F. Casu “Generation and analysis of spaceborne DInSAR products to support Civil Protection activities in volcanic and seismic regions”, *XII° AIT International Conference (Smart Earth Observation for a Sustainable Future)*.
- P. Noli, M. Bonano, S. Buonanno, F. Casamento, F. Casu, F. Cotugno, C. De Luca, **M. Franzese**, A. Fusco, M. Manunta, F. Monterroso, G. Onorato, Y. Roa, P. Striano, M. Yasir, G. Zeni, I. Zinno and R. Lanari “DInSAR time-series automatic generation of the Italian territory by exploiting Sentinel-1 SAR data archives through the P-SBAS approach”, *XII° AIT International Conference (Smart Earth Observation for a Sustainable Future)*.
- P. Striano, M. Bonano, S. Buonanno, F. Casamento, F. Casu, F. Cotugno, C. De Luca, **M. Franzese**, A. Fusco, M. Manunta, F. Monterroso, P. Noli, G. Onorato, Y. Roa, M. Yasir, G. Zeni, I. Zinno and R. Lanari “Extensive Full Resolution P-SBAS analysis for monitoring critical displacements related to the built-up environment over the Italian territory”, *XII° AIT International Conference (Smart Earth Observation for a Sustainable Future)*.

5. Conferences and seminars attended

- IEEE International workshop on Technologies for Defense and Security 2024, Napoli, 11-13 Nov. 2024.
- Living Planet Symposium 2025, Vienna, Austria, 23-27 Jun 2025.

6. Periods abroad and/or in international research institutions

None

7. Tutorship

None

8. Plan for year three

Research activities:

During the third year, the research activity will focus on the analysis and modeling of the ionospheric impact at single-image level, with the goal of developing a focusing correction strategy capable of compensating ionospheric distortions directly within each Single-Look Complex (SLC) image. In contrast to previous approaches, based on the interferometric processing of image pairs, the new methodology aims to estimate the ionospheric impact on each SLC image Doppler history, thus allowing the correction of azimuth defocusing and geometric distortions induced by ionospheric irregularities. This additional level of analysis is intended to improve the understanding of ionospheric effects on the SAR focusing process and to enhance the quality of deformation measurements.

Research period abroad:

From February to July 2026 at the German Aerospace Center (DLR), Oberpfaffenhofen, Germany.

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Draft topic or title of the thesis:

Development of advanced algorithms for the detection and mitigation of ionospheric effects in L-band SAR images.