Innovation in InSAR Processing and Analysis of C-, X- and L-Band SAR Data for Natural Hazards, Agriculture, Marine and Coastal Applications in the framework of ASI's "Multi-Mission and Multi-Frequency SAR" Program

Deodato Tapete, Antonio Montuori, Fabrizio Lenti, Patrizia Sacco, Maria Virelli, Simona Zoffoli, Alessandro Coletta

Italian Space Agency (ASI)

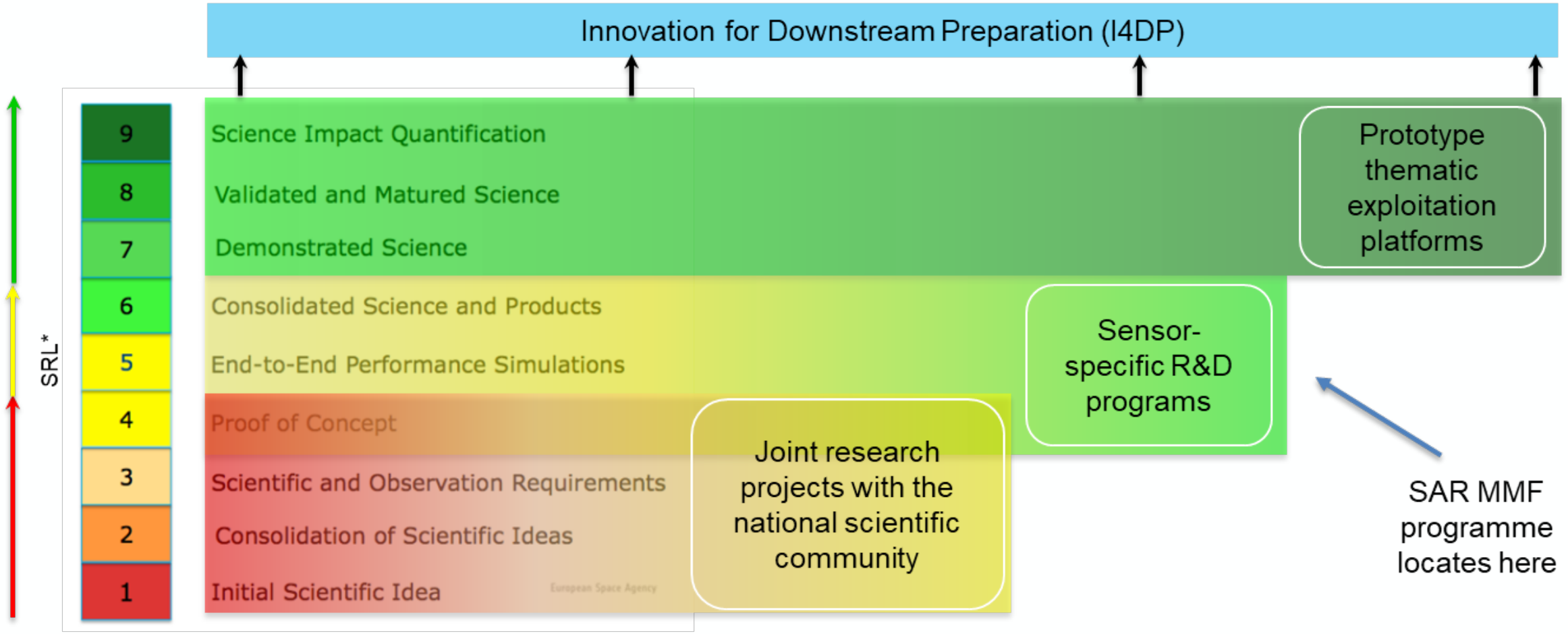
FRINGE 2023

University of Leeds, UK | 11 - 15 September 2023

Sensor-specific R&D program: Multi-mission & multi-frequency SAR

- **10 R&D projects** (from April 2021 to July 2023) about methods, techniques & algorithms for *exploitation* of multi-mission & multi-frequency SAR data, also integrated with other types of EO and/or non-EO data
- **Focus on L-band SAR (e.g. SAOCOM)**, also in relation to ASI-CONAE SIASGE cooperation
- **Pre-operational projects**, based on innovative ideas & algorithms, with credible perspectives of engineering and pre-operational development
- Update the background and needs of the SAR user community to support and define **medium-to-long term strategies** of new EO applications
- In turn, enable user-driven applications → **scientific downstream**
- Support the SAR-based research activities carried out by public and private national community – **also in cooperation with international partners** –, contributing to maintain a leading position within the international context

ASI's initiatives & scientific downstream portfolio



* SRL – *Scientific Readiness Level* as per the definition in the European Space Agency (ESA) SRL Handbook EOP-SM/2776

R&D areas of specific interest & ASI projects

Agriculture

- SARAGRI
- CLEXIDRA
- MultiBigSARData

Cryosphere

- CRIOSAR
- SMIVIA

Urban areas

- MultiBigSARData

Sea & coast

- APPLICAVEMARS
- COAST

Natural hazards

- MUSAR
- MEFISTO
- DInSAR-3M

Validation of products generated from multi-frequency SAR data by using ground-truth data

ASI's Multi-mission & multi-frequency SAR projects @ FRINGE 2023 – Part 1

Where and when you can hear about ASI's Multi-mission & multi-frequency SAR projects @ FRINGE 2023

2.03.a: Ice and Snow 2
Time: 12/Sept/2023: 2:00pm-3:40pm · Location: Auditorium I

CRIOSAR

3:00pm - 3:20pm
Oral_20

Assessing Rock Glacier Activity In Val Senales By Exploiting Multiband SAR Data Through Differential SAR Interferometry And Offset Tracking

Fabio Bovenga[1], Ilenia Argentiero[1], Antonella Belmonte[1], Alberto Refice[1], Giovanni Cuozzo[2], Melisa Soledad Heredia[2], Mattia Callegari[2], Claudia Notarnicola[2], Davide Oscar Nitti[3], Raffaele Nutricato[3]
[1]Institute for Electromagnetic Sensing of the Environment, National Research Council of Italy (CNR-IREA); [2]EURAC Research - Institute for Earth Observation; [3]GAP s.r.l.

POSTER SESSION
Time: 12/Sept/2023: 4:30pm-7:00pm · Location: Poster Session/Exhibition

CRIOSAR

Multi-band SAR Interferometry For Snow Water Equivalent Estimation Over Alpine Mountains

Fabio Bovenga[1], Antonella Belmonte[1], Alberto Refice[1], Ilenia Argentiero[1], Simone Pettinato[2], Emanuele Santi[2], Simonetta Paloscia[2]
[1]Institute for Electromagnetic Sensing of the Environment, National Research Council of Italy (CNR-IREA); [2]Institute of Applied Physics, National Research Council of Italy (IFAC-CNR)

POSTER SESSION
Time: 12/Sept/2023: 4:30pm-7:00pm · Location: Poster Session/Exhibition

MUSAR

"The Data Fusion Application for a Multifrequency Post-processing Analysis of A-DInSAR Data"

Niccolò Belcecchi[1], Gianmarco Pantozzi[1], Carlo Alberto Stefanini[1], Paolo Mazzanti[1,2], Alessandro Brunetti[1], Michele Gaeta[1]
[1]NHAZCA Srl, Via V. Bachelet 12, Rome 00185, Italy; [2]Dipartimento di Scienze della Terra, Università degli studi di Roma "La Sapienza", Piazzale Aldo Moro 5, Rome 00185, Italy

ASI's Multi-mission & multi-frequency SAR projects @ FRINGE 2023 – Part 2

Where and when you can hear about ASI's Multi-mission & multi-frequency SAR projects @ FRINGE 2023

5.01.a: C-and L-band synergies: ESA-JAXA cooperation and beyond
Time: 15/Sept/2023: 9:00am-10:40am · Location: Auditorium I

DInSAR-3M

Oral_20

On the P-SBAS Processing Chain New Developments For The Generation Of SAOCOM-1 Advanced DInSAR Products

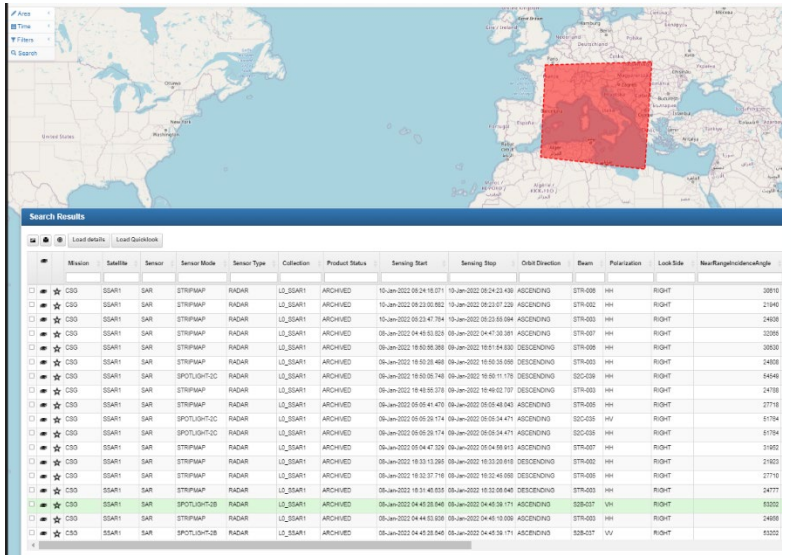
Claudio De Luca[1], Yenni Lorena Belen Roa[1], Manuela Bonano[1], Francesco Casu[1], Leonardo Euillades[2], Pablo Euillades[2], Marianna Franzese[1], Michele Manunta[1], Yasir Muhammad[1], Giovanni Onorato[1], Pasquale Striano[1], Ivana Zinno[1], Riccardo Lanari[1]

[1]Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), CNR, Napoli, Italy; [2]Conicet, Instituto CEDIAC, Facultad de Ingenierìa, Universidad Nac de Cuyo, Mendoza, Argentina

Facilitated accessibility to satellite SAR data

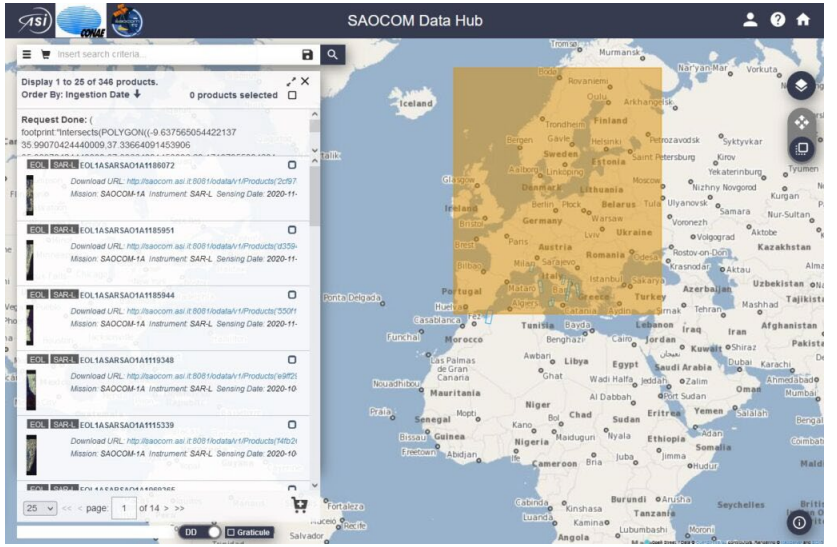
COSMO-SkyMed First & Second Generation (CSK & CSG)

- New portal for institutional users (https://portal.cosmo-skymed.it/CDMFE/home)
- Opportunity to task CSG to concatenate temporally and spatially with existing archive CSK images, and thus achieve observation continuity
- Over Italy, through MapItaly Project



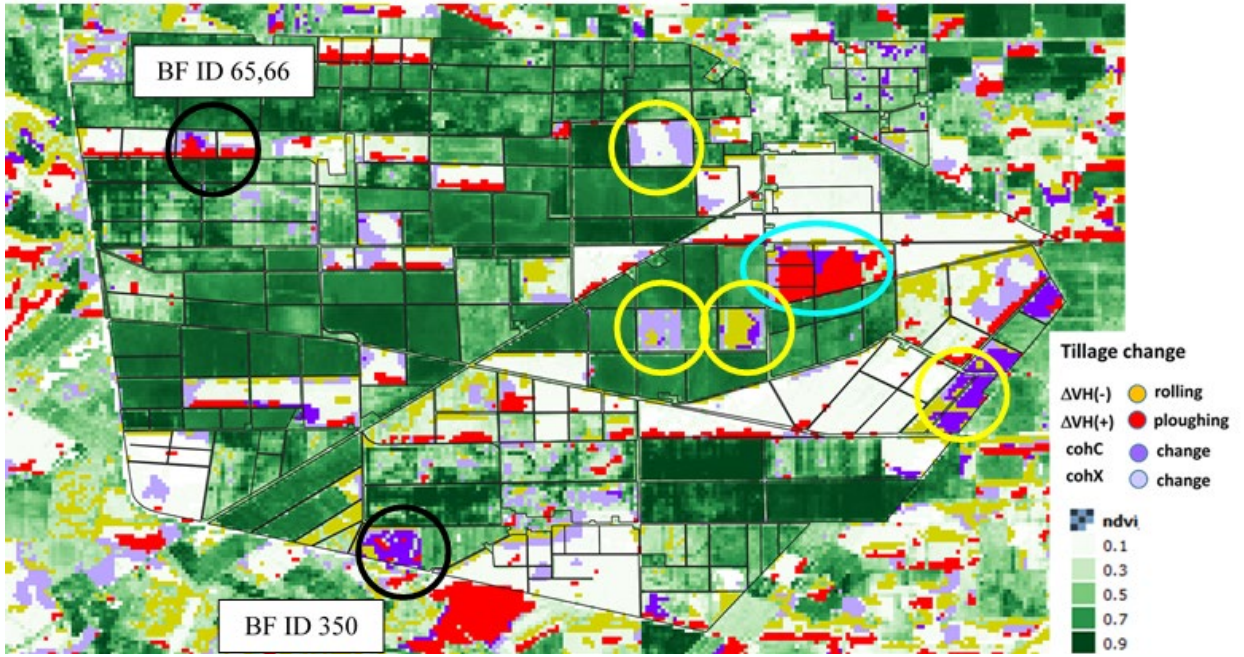
SAOCOM

- New dedicated ASI portal (http://saocom.asi.it:8081)
- Data dissemination over the “Zone of Exclusivity” (ZoE; 10W-50E longitude range and 30-80N latitude range), currently via:
  - Archive imagery provision service
  - Beta-testing for ordering new acquisitions & products
- The experience led to current systematic acquisition plan over Italy and Europe



Achievements in CSK & CSG data exploitation

- Total amount of products provided as of July 2023: 5787 (5045 archive and 742 new tasking)
- Mostly in StripMap mode, single pol, for interferometric and change detection analyses
- CSG satellites also tasked to collect series of quad-pol StripMap images to test the enhanced polarimetric capabilities compared to what previously allowed by CSK, e.g. for maritime applications.
- Furthermore, by adding CSG satellites into the MapItaly Project since nearly the beginning of the program, the temporal revisit at X-band was much improved **up to 1 day (tandem pairs)**. Benefits for time-sensitive applications or requiring higher frequency of observations.



Tillage change map over Jolanda di Savoia based on a 2-day revisit CSG-CSK pair, where X-band coherence improves the detection of known tillage events (black circles) and identifies additional areas (light purple) compared to C-band 6-day Sentinel-1 coherence (**image courtesy: CNR-IREA, SARAGRI project**).

SARAGRI: S1 tillage change detection

- Original algorithm (Satalino et al., 2018) incoherent change detection applied to S1- cross-pol over bare soils
- Multi-scale approach to separate precipitation effects (medium-scale) on backscatter.

Example of tilled/non-tilled fields by S1 cross-pol change and S-2 NDVI (≤0.3) @100m scale

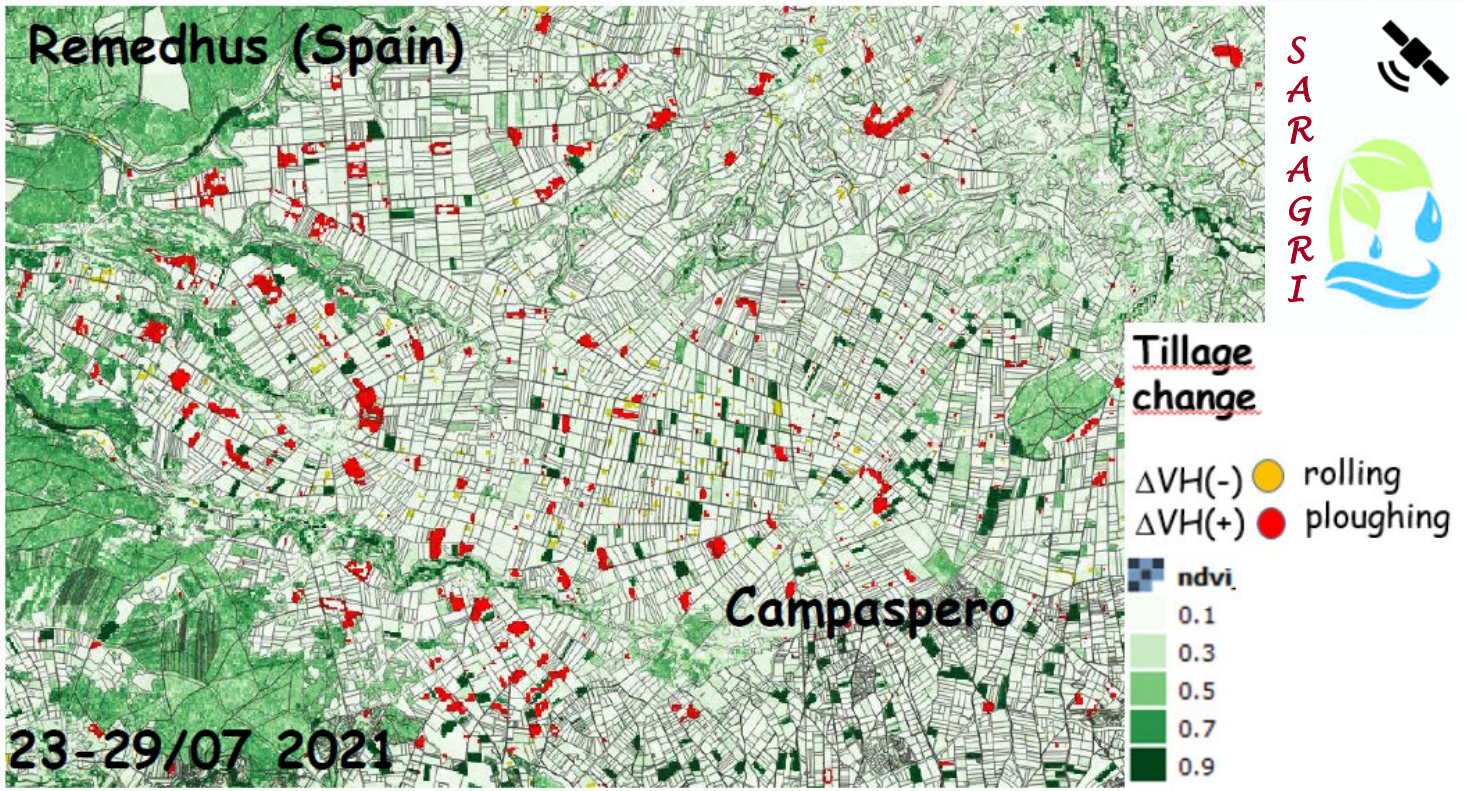
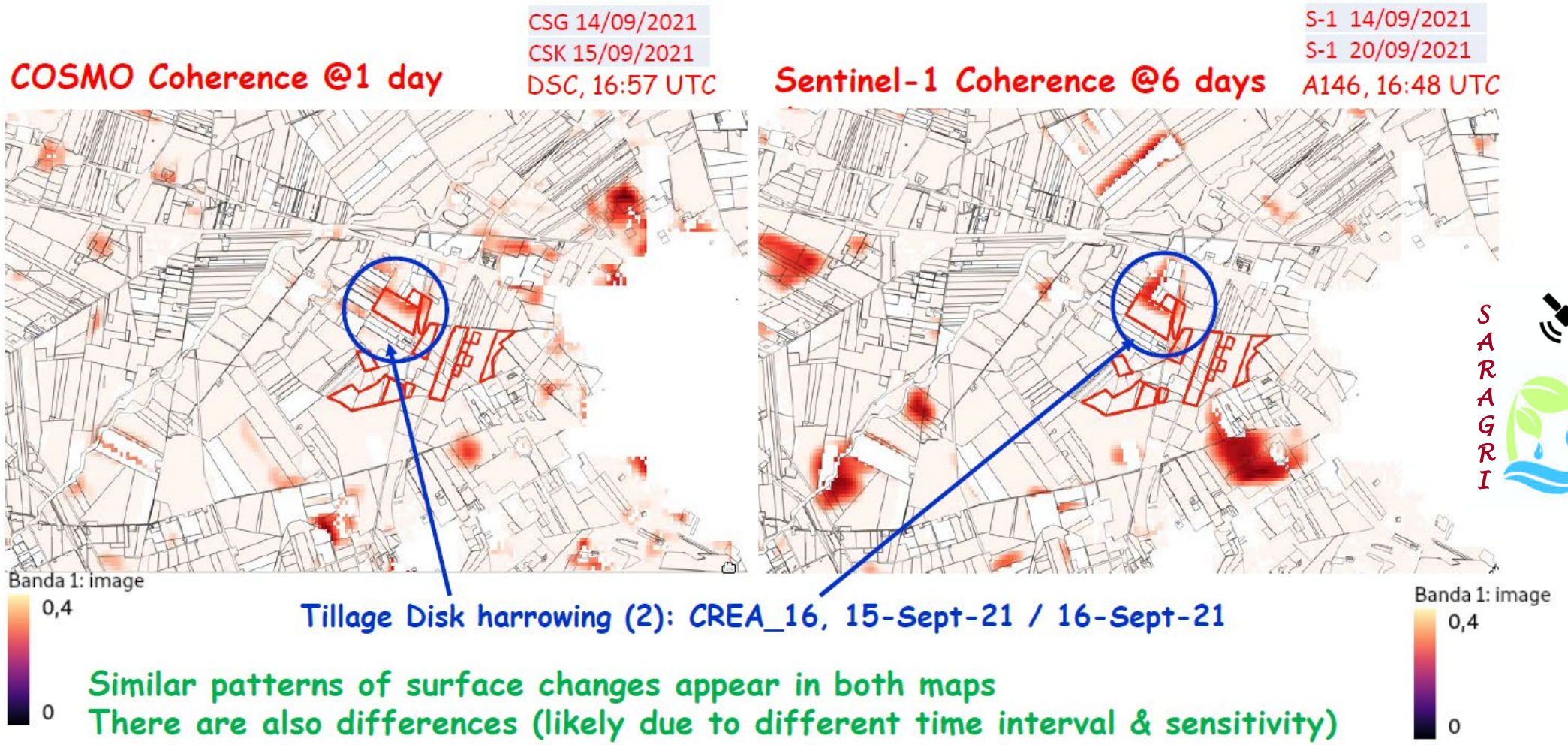


image courtesy: CNR-IREA, SARAGRI project

Satalino *et al*. (2018) "Sentinel-1 & Sentinel-2 Data for Soil Tillage Change Detection," *IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium*, Valencia, Spain, 2018, pp. 6627-6630, doi: 10.1109/IGARSS.2018.8519103.

SARAGRI: Integrating incoherent & coherent change detection

image courtesy: CNR-IREA, SARAGRI project

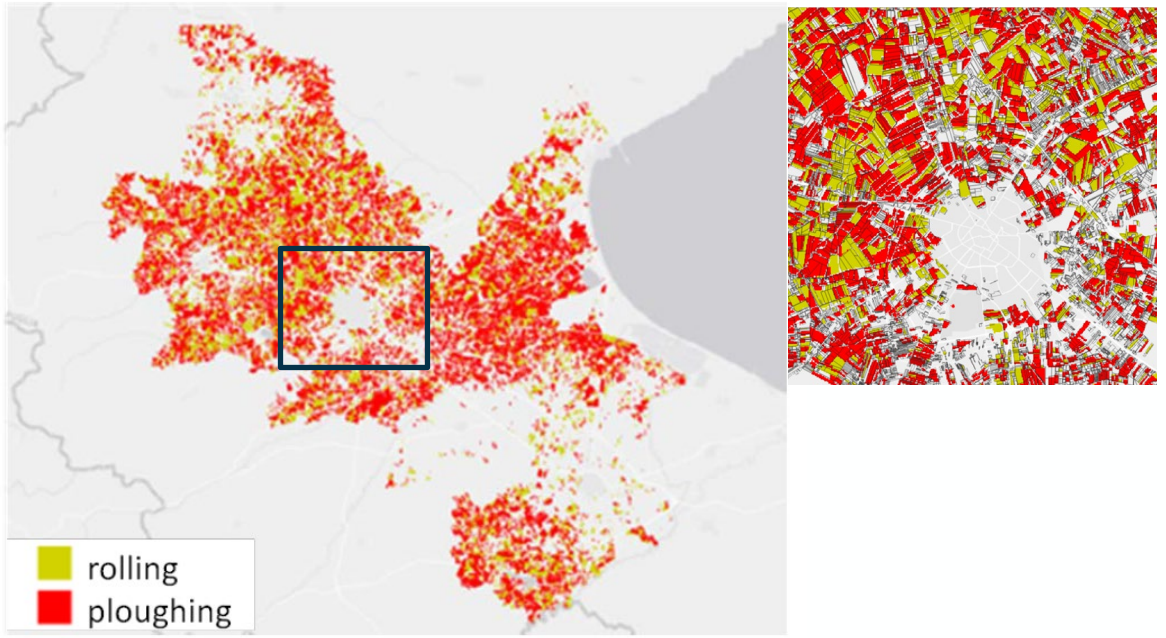


SARAGRI: tillage practices products

Apulian Tavoliere site (southern Italy)

Potential use: early estimation of the cultivated area of the winter or summer crops

S1- based seasonal cumulative map of agricultural practices 01/09 – 30/11/2021



S2 NDVI area estimated on 12/04/2022

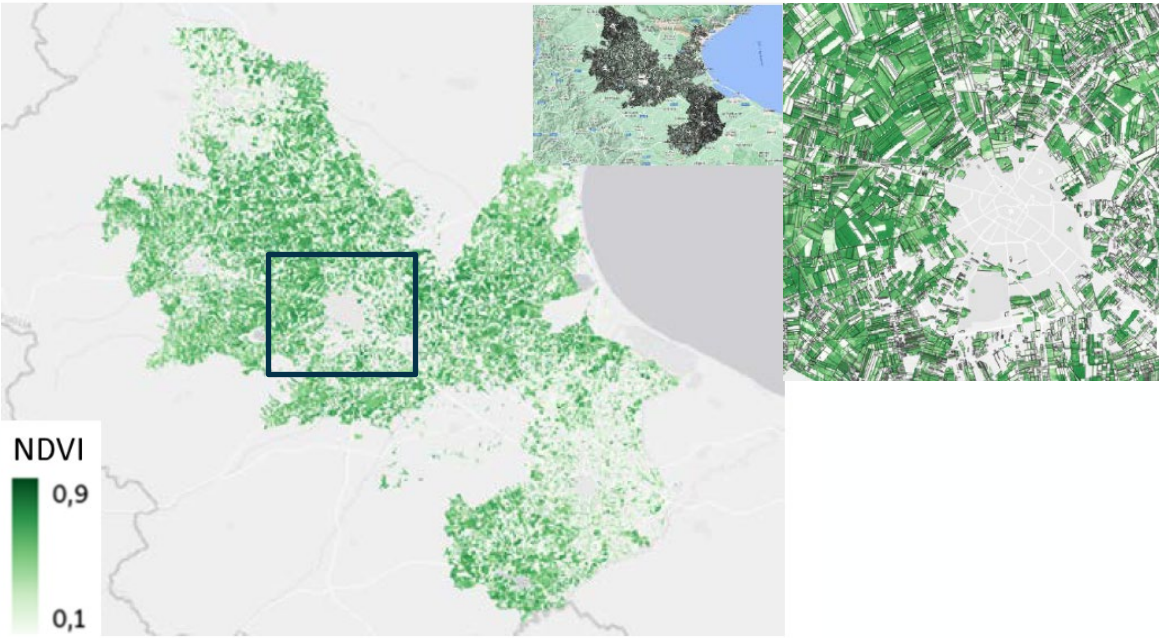
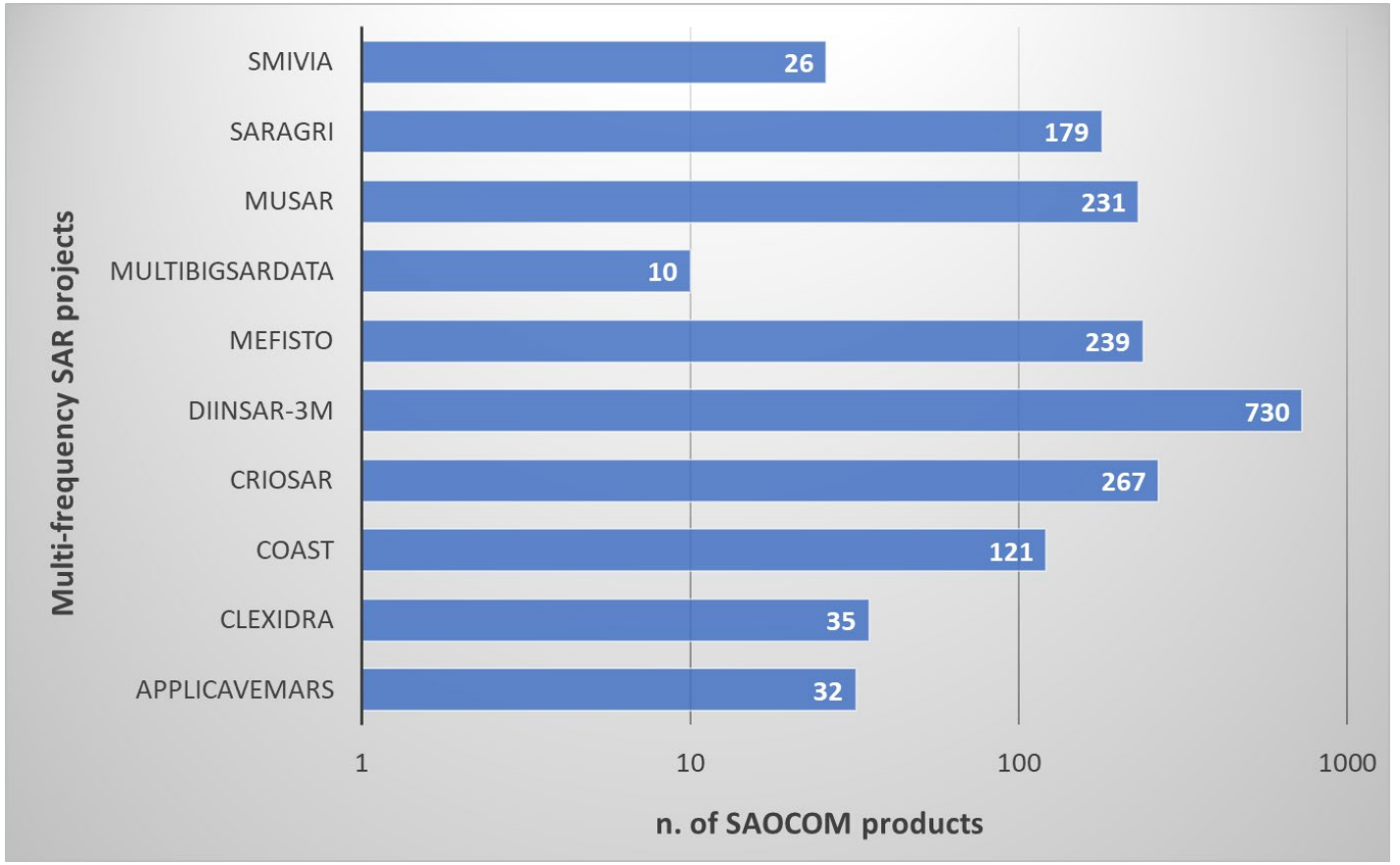


image courtesy: CNR-IREA, SARAGRI project

Achievements in SAOCOM data exploitation

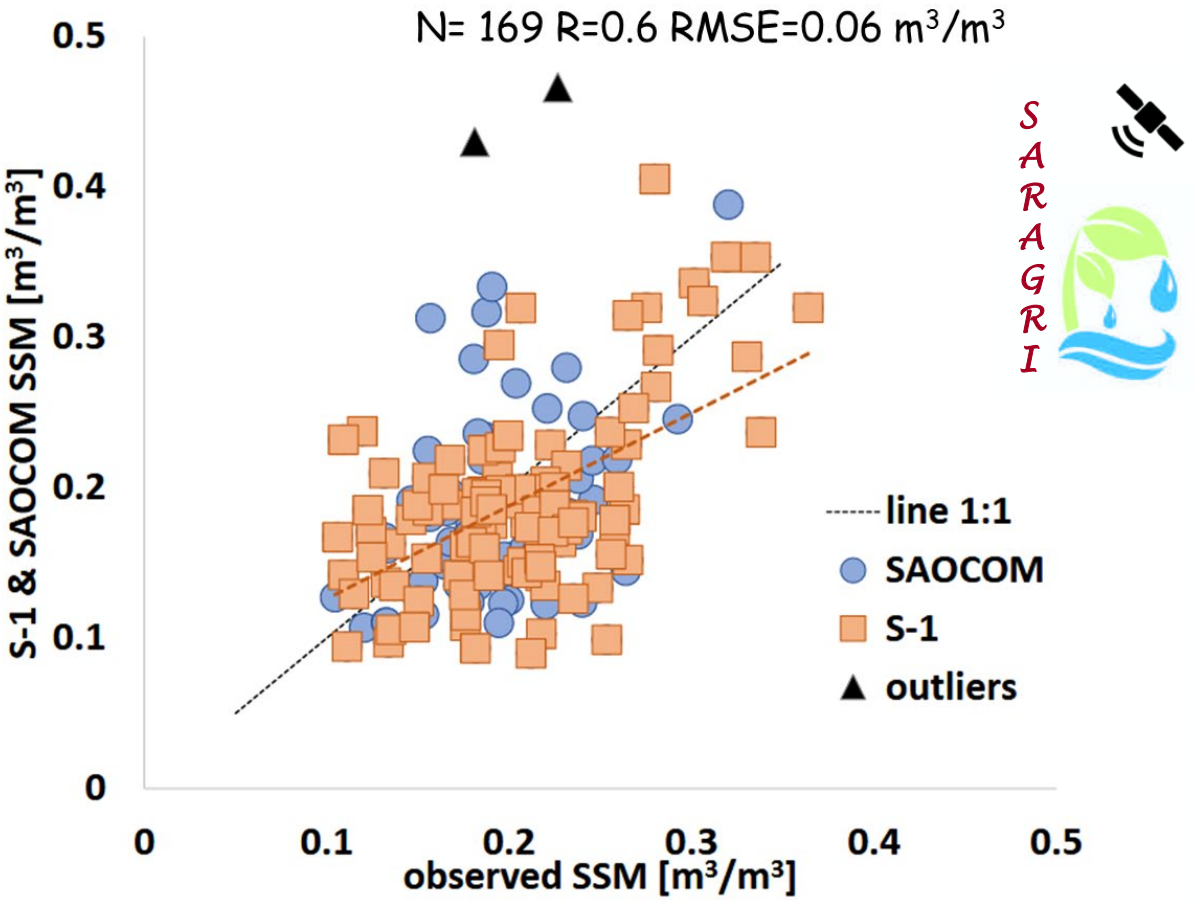
- SAR MMF program was an opportunity for ASI to boost the exploitation phase of SAOCOM L-band data within the ZoE
- Total amount of products provided as of May 2023: **1870**
- After more than 1 year of implementation, at least 20 SAOCOM images per single geometry each AOI
- Best revisit times = 8 days in each geometry (i.e. SAOCOM-1A and 1B)
- Ad hoc acquisitions of quad-pol StripMap images. Benefits e.g. for model inversion and improvement of soil moisture retrieval (CLEXIDRA)



SARAGRI: Combining S1 & SAOCOM for SSM retrieval

- Interoperability of Sentinel-1 & SAOCOM platforms for SSM retrieval, **to improve temporal resolution**

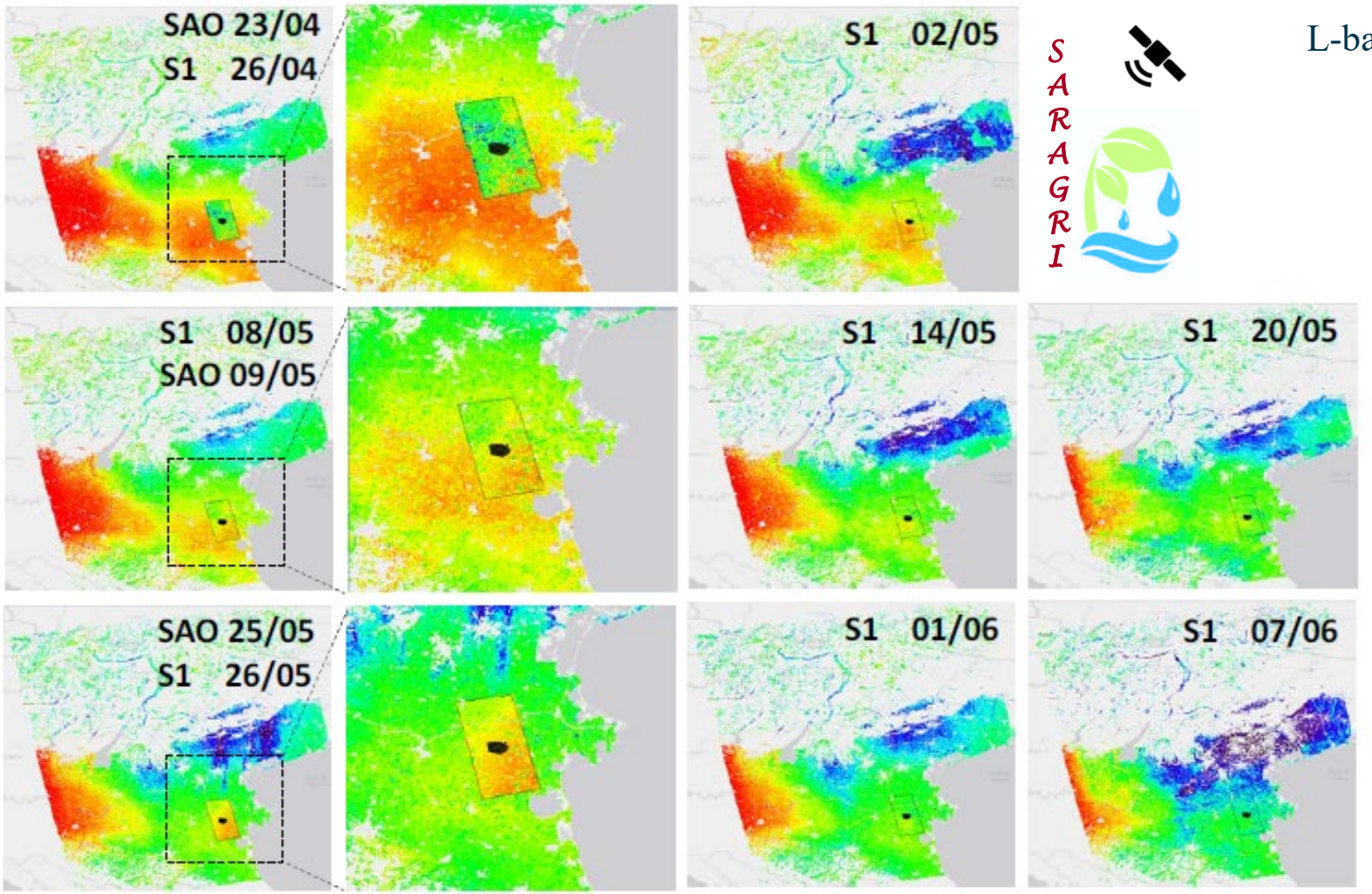
- Dense time series of SAR data → incoherent short term change detection
  (5 and 3 days on average for Apulian Tavoliere and Jolanbda di Savoia, resp.)



Scatterplot of S-1 (orange squares) and SAOSOM (blue points) SSM vs. SSM observed over the Apulian Tavoliere and Jolanda di Savoia sites. Two outliers (3 sigma) are in black triangles. Line 1:1 in black

image courtesy: CNR-IREA, SARAGRI project

SARAGRI: Combining S1 & SAOCOM for SSM retrieval



L-band SAOCOM compared with C-band Sentinel-1

Time series of multi-frequency SSM maps derived from Sentinel-1 and A-SAOCOM between April and June 2020 over Jolanda di Savoia, Italy.

The SAOCOM SSM maps are superimposed over the closest Sentinel-1 SSM maps.

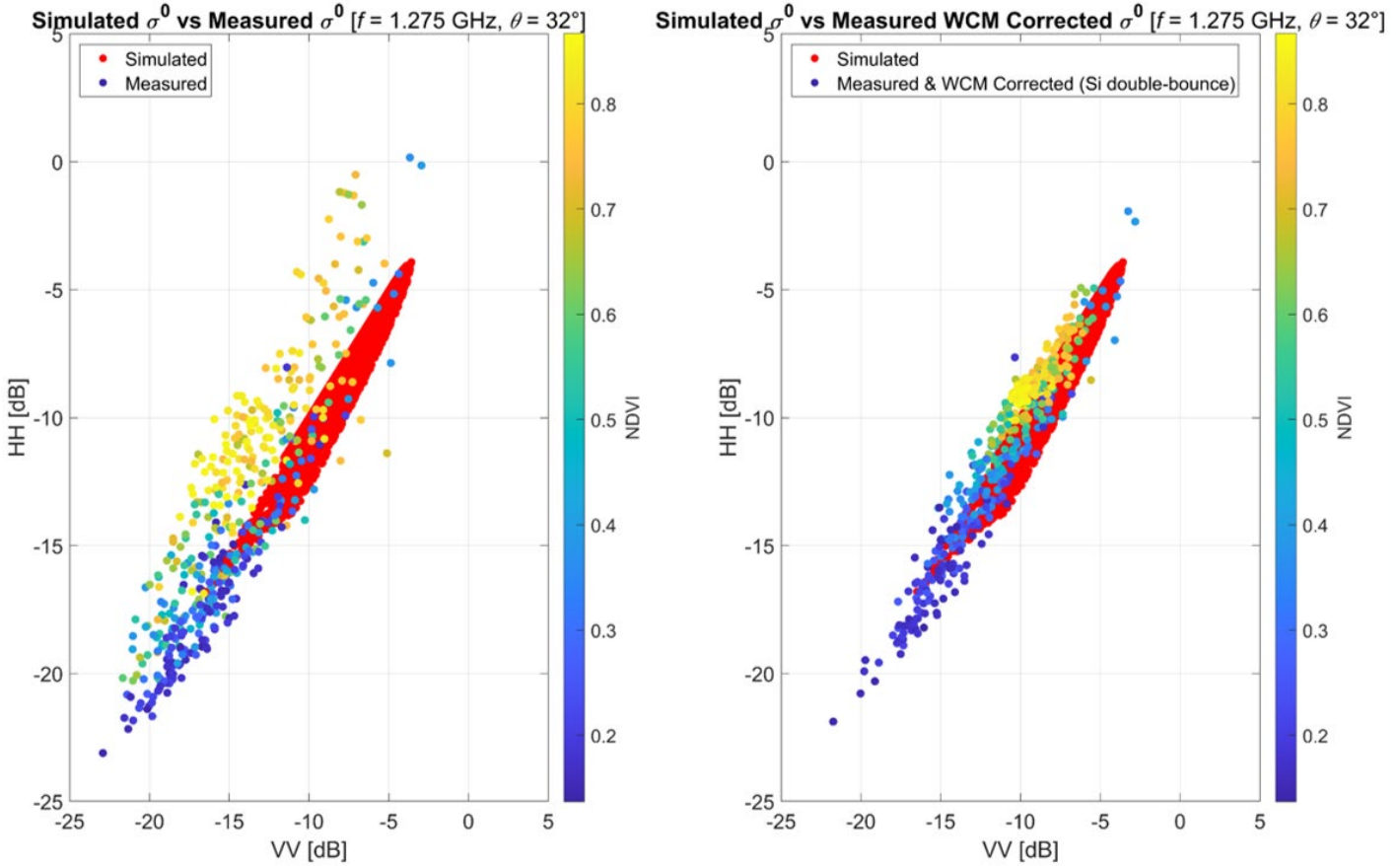
The black rectangle corresponds to the SAOCOM footprint

CLEXIDRA: SAOCOM SM retrieval vs. models

Objectives: Develop an automatic SM retrieval algorithm by means of bare and vegetated soil scattering models inversion, Bayesian minimization and machine learning techniques

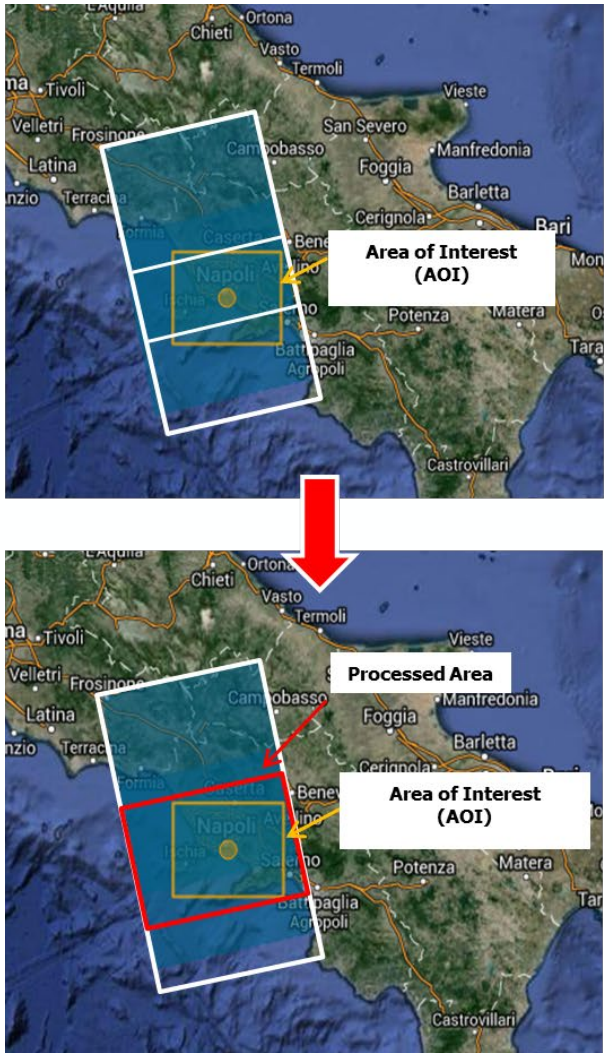
(left) for low NDVI values the data are in line with the model; however, both HH and VV co-polarized SAR backscattering coefficients are overestimated. For high NDVI values a deviation from the model is noted.

(right) the points characterized by high NDVI values tend to approach the values simulated by the model after the calibration of the Water Cloud Model (WCM) and after applying it to the SAR data in order to correct the effects of vegetation.



Comparison of soil scattering between data simulated by the Semi Empirical Model (SEM - red dots) and **SAOCOM dataset** acquired over the Monte Buey site (Argentina), corrected or not for vegetation effects with the Water Cloud Model (colored dots) (**image courtesy: CLEXIDRA project**).

DInSAR-3M: SAOCOM full processing InSAR chain



Block diagram of the implemented procedure related to the ingestion, merging and cut of the **SAOCOM L1A SAR data**.

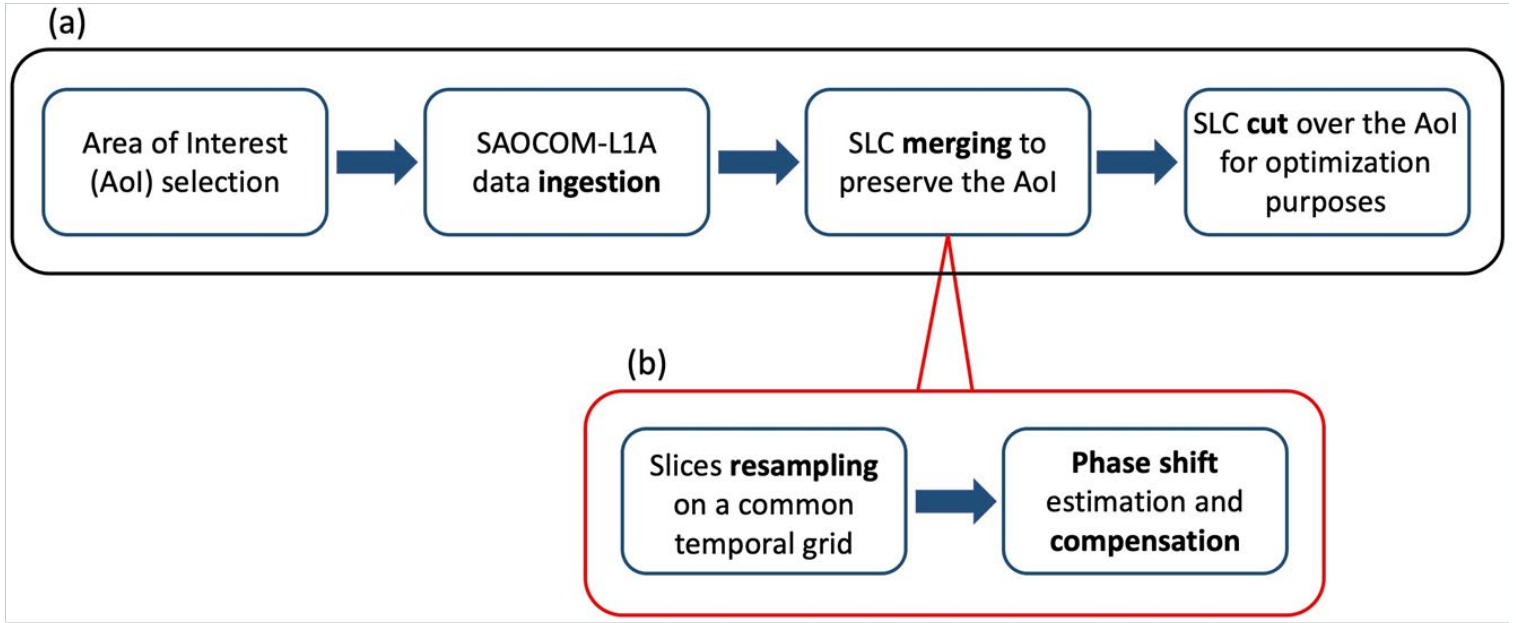
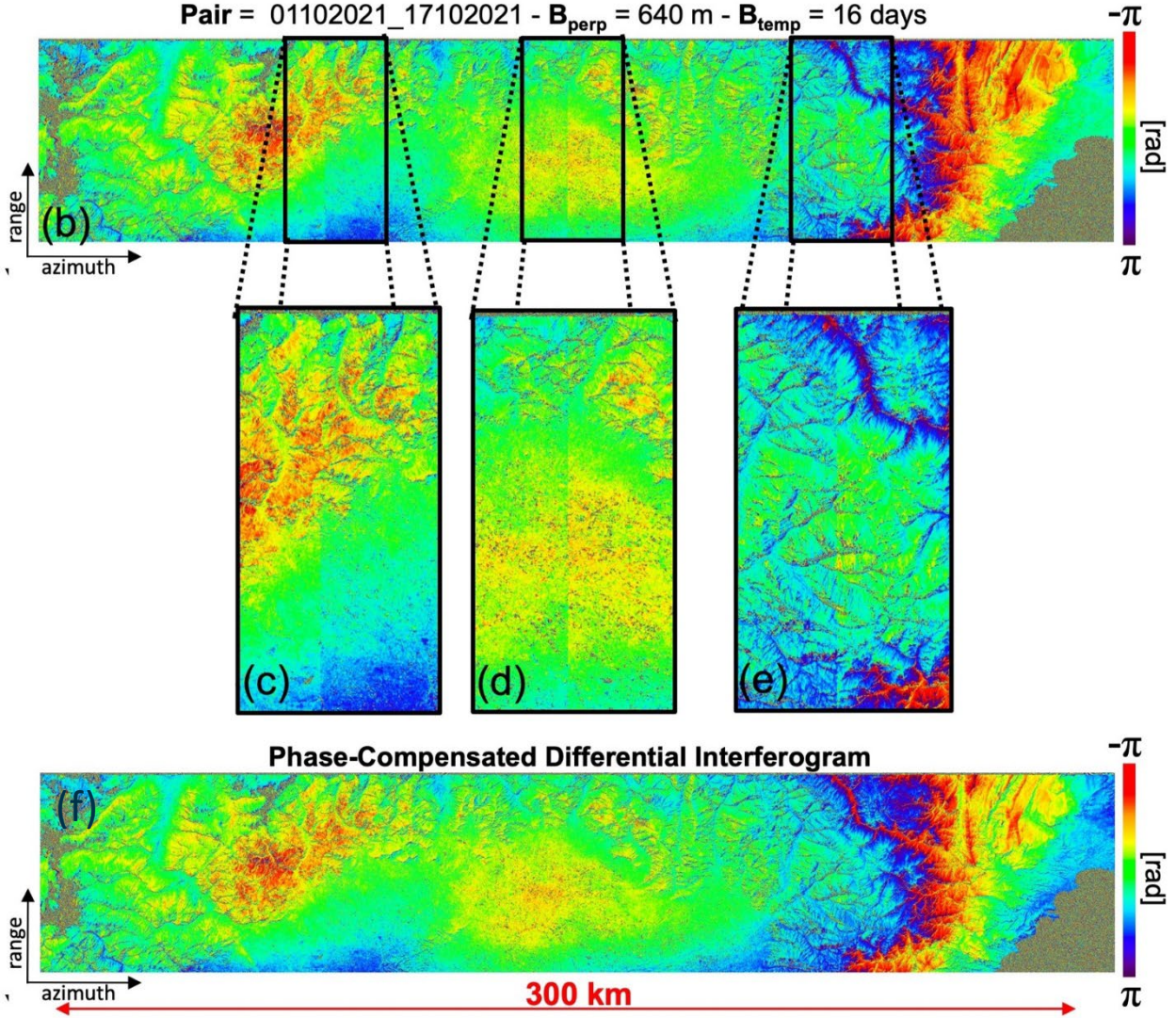


image courtesy: CNR-IREA, DInSAR-3M project

DInSAR-3M: SAOCOM full processing InSAR chain



Multiple-slice phase shift estimation and compensation

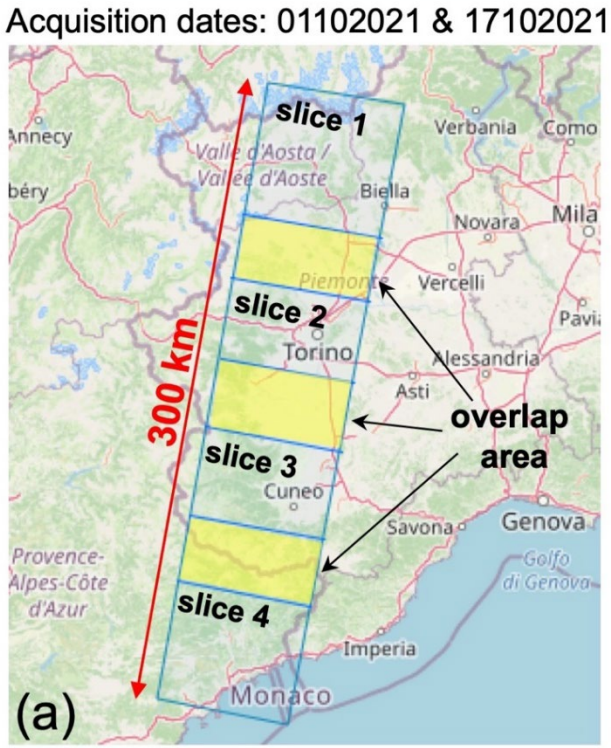
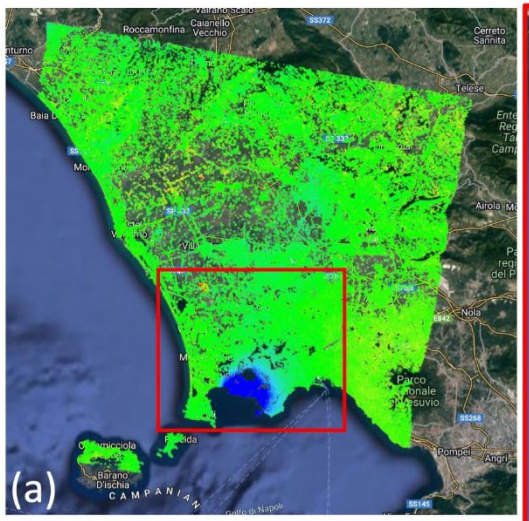
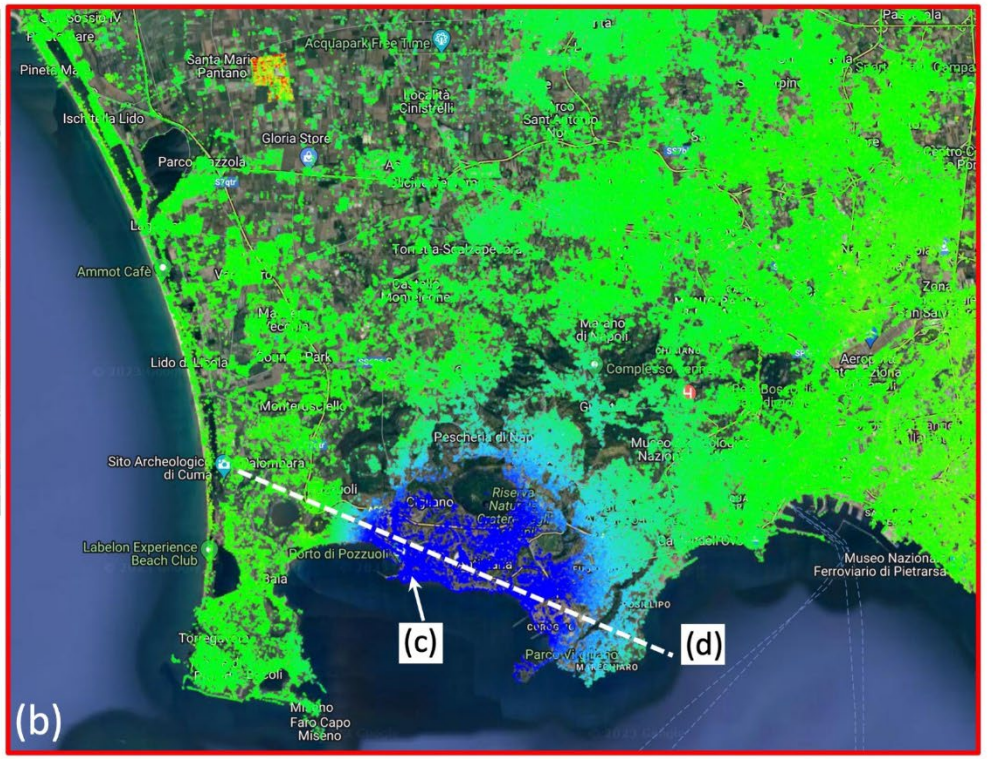


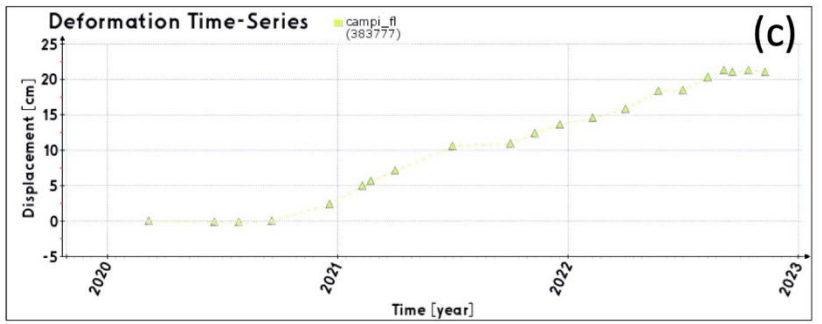
image courtesy: CNR-IREA, DInSAR-3M project

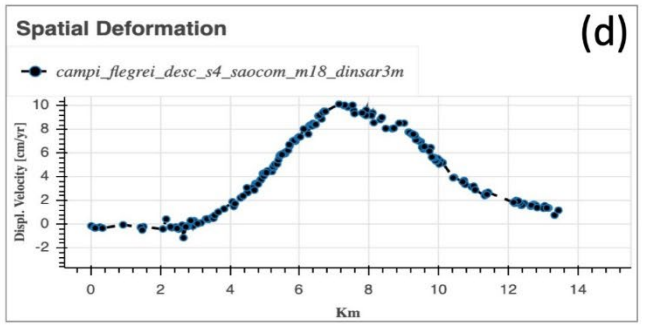
DInSAR-3M: SAOCOM full processing InSAR chain





Mean LOS velocity
-3< >3
[cm/year]





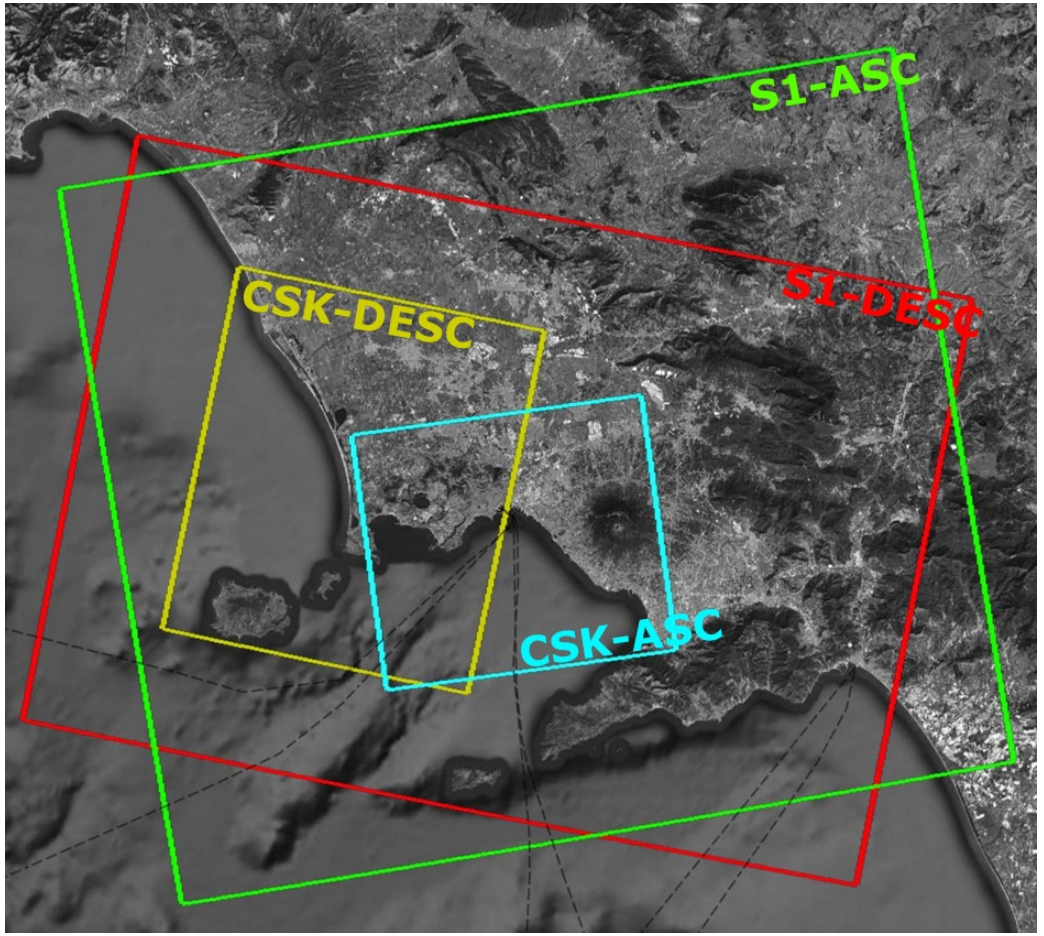
Descending (swath: S4, path: 108) SAOCOM-1 dataset (21 images) relevant to the Campi Flegrei caldera AoI: (a-b) overall mean deformation velocity map; (c) plot of the displacement time-series in a pixel located within the Pozzuoli harbour, which represents the area affected by the maximum of the displacement; (d) profile of the mean deformation velocity values along a section (white line).

More details in the oral presentation by De Luca et al. @ FRINGE 2023

Tomorrow morning, Session 5.01.a: C-and L-band synergies: ESA-JAXA cooperation and beyond Time Location: Auditorium I

image courtesy: CNR-IREA, DInSAR-3M project

DInSAR-3M: Multi-frequency and multi-platform data integration



General expression

$$\begin{cases} v_{losA_1} = v_U \cos\vartheta_{A_1} - v_E \sin\vartheta_{A_1} \cos\alpha_{A_1} - v_N \sin\vartheta_{A_1} \sin\alpha_{A_1} \\ v_{losD_1} = v_U \cos\vartheta_{D_1} + v_E \sin\vartheta_{D_1} \cos\alpha_{D_1} - v_N \sin\vartheta_{D_1} \sin\alpha_{D_1} \\ \cdot \\ \cdot \\ \cdot \\ v_{losA_j} = v_U \cos\vartheta_{A_j} - v_E \sin\vartheta_{A_j} \cos\alpha_{A_j} - v_N \sin\vartheta_{A_j} \sin\alpha_{A_j} \\ v_{losD_j} = v_U \cos\vartheta_{D_j} + v_E \sin\vartheta_{D_j} \cos\alpha_{D_j} - v_N \sin\vartheta_{D_j} \sin\alpha_{D_j} \end{cases} \quad \text{with} \quad 1 \le j \le M, j \in \mathbb{N}$$

Expression for SSO satellite platforms

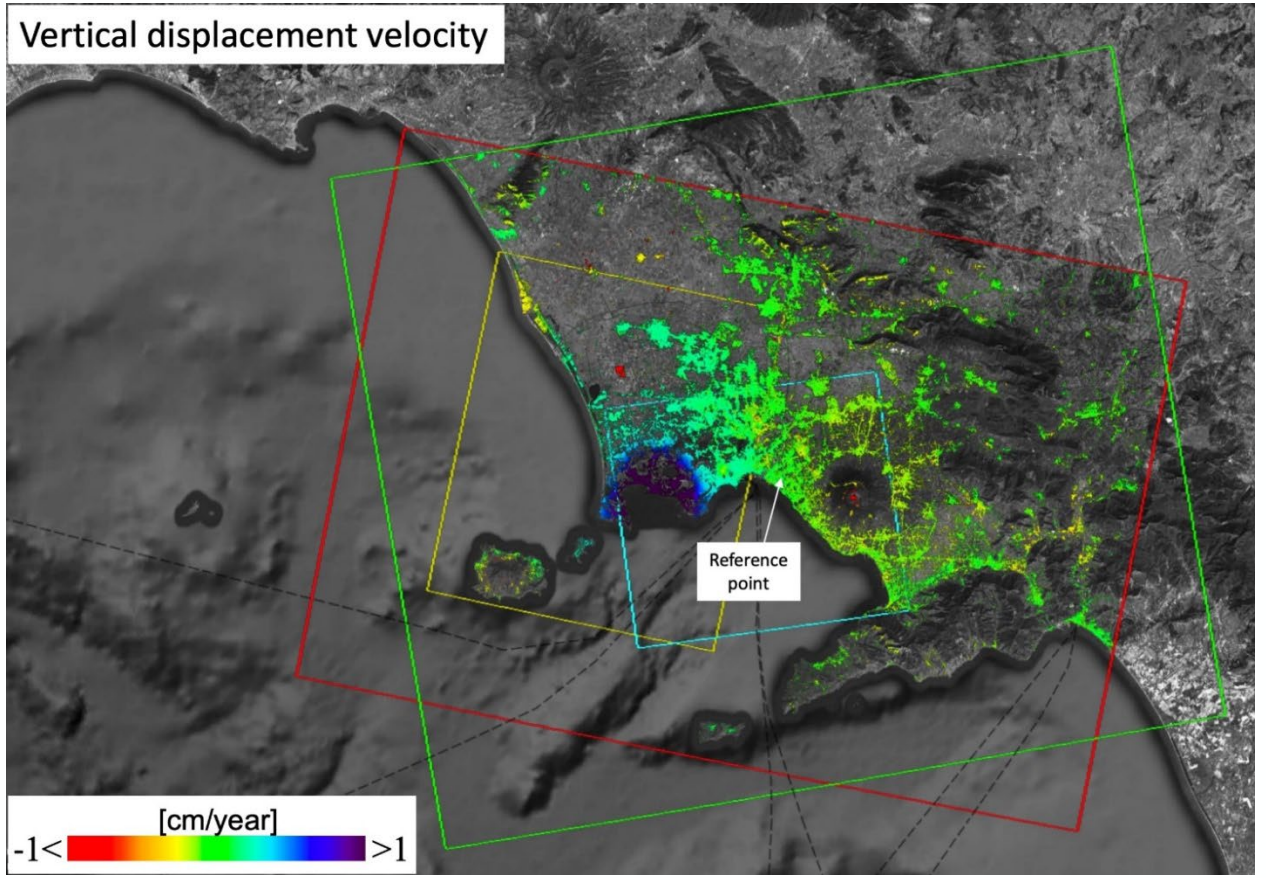
$$\begin{cases} v_{losA_1} = v_U \cos\vartheta_{A_1} - v_E \sin\vartheta_{A_1} \\ v_{losD_1} = v_U \cos\vartheta_{D_1} + v_E \sin\vartheta_{D_1} \\ \cdot \\ \cdot \\ \cdot \\ v_{losA_j} = v_U \cos\vartheta_{A_j} - v_E \sin\vartheta_{A_j} \\ v_{losD_j} = v_U \cos\vartheta_{D_j} + v_E \sin\vartheta_{D_j} \end{cases} \quad \text{with} \quad 1 \le j \le M, j \in \mathbb{N}$$

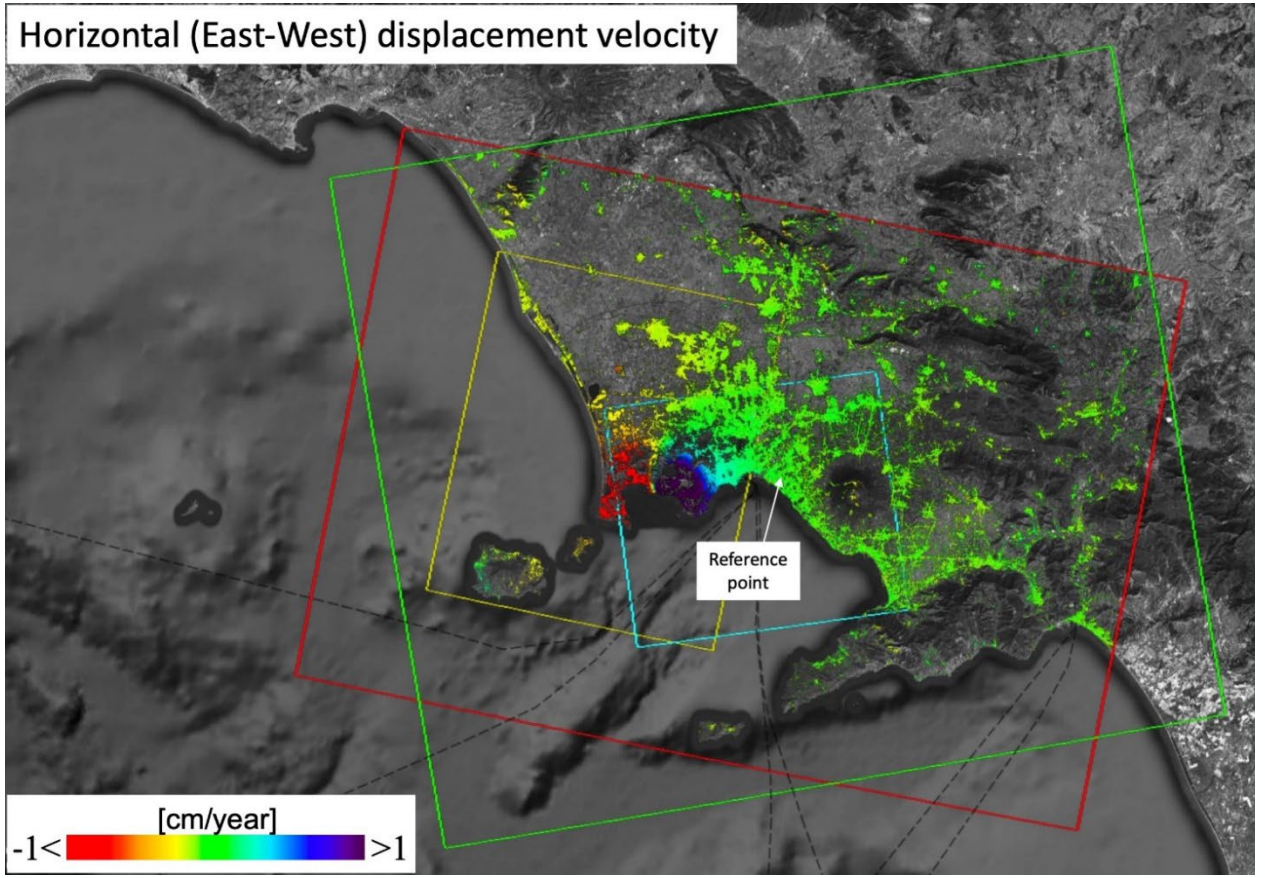
image courtesy: CNR-IREA, DInSAR-3M project

DInSAR-3M: Multi-frequency and multi-platform data integration

(left) map of the retrieved vertical displacement component; (right) the corresponding horizontal one, which are single-point referenced.

As evident by observing the displacement components, the algorithm retrieves the deformation not only over the common geometric area, but also over the other areas **where coherent pixels for at least two independent acquisition geometries are available**.





MUSAR: Multi-frequency and multi-platform data integration

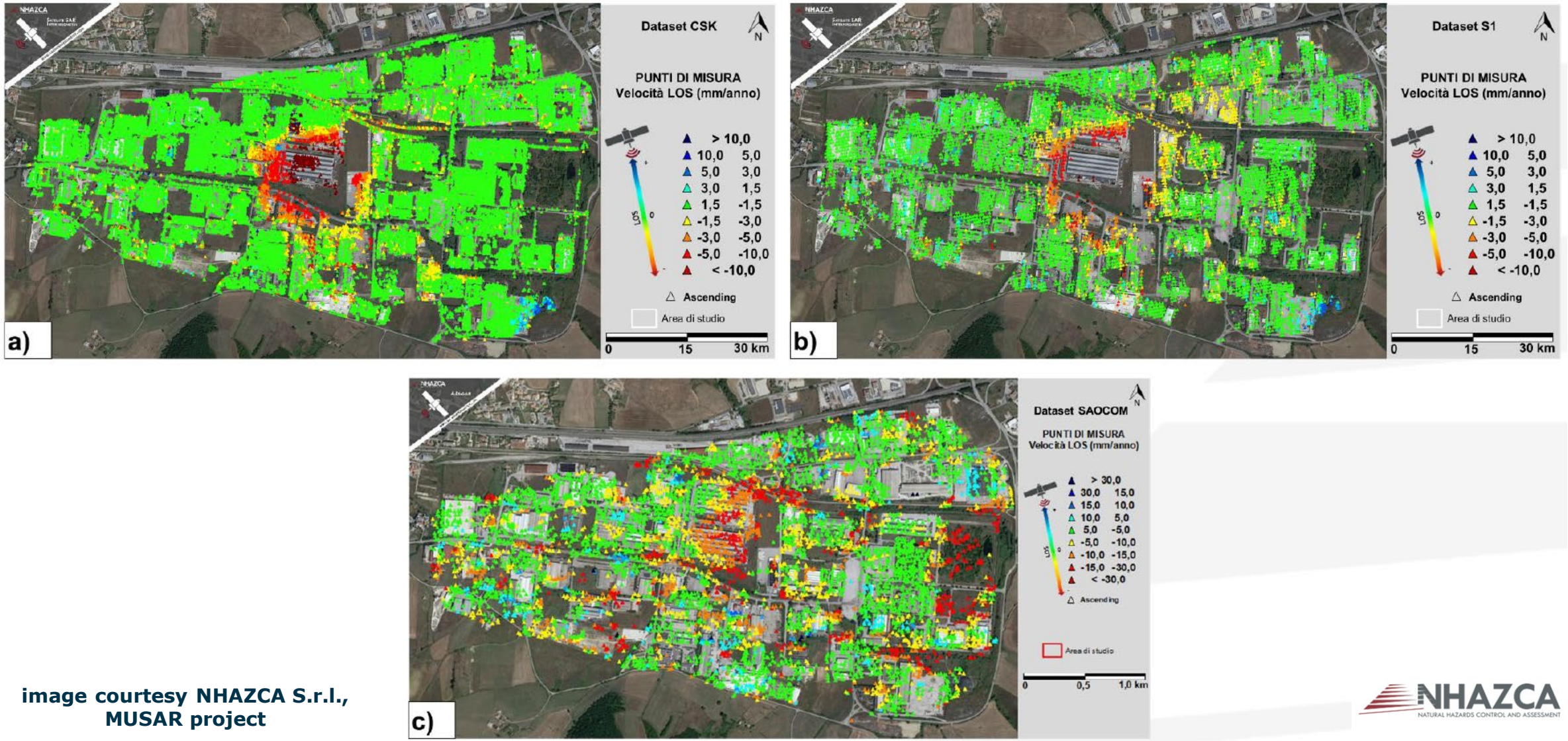


image courtesy NHAZCA S.r.l., MUSAR project

MUSAR: Multi-sensor InSAR data fusion

NHAZCA S.r.l. developed a mathematical model by which displacement components fi (Xp) (i =1..3) can be estimated in the generic point Xp=(xp,yp,zp) by integrating Photomonitoring measurements (f1 (Xj), f2 (Xj)) j=1..M and the DLOSk (X) (k=1..Q) measurements, either DInSAR measurements or PS displacements, by using the linear equation system.

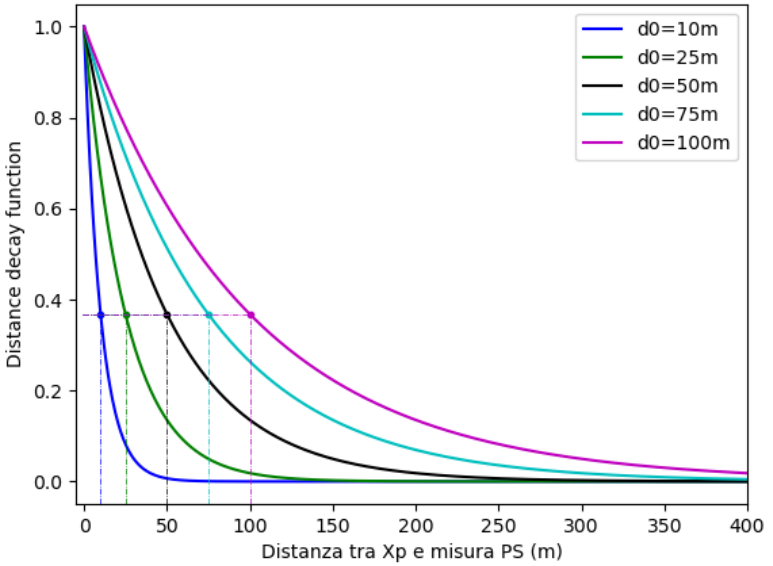
$$\begin{cases} f_i(X_p) + \nabla f_i(X_p)\Delta X = f_i(X_j)\,, i = 1..2, \qquad j = 1..M \\ D^k_{LOS}(X_p) + \nabla D^k_{LOS}(X_p)\Delta X = D^k_{LOS}(XS_d)\,, k = 1..Q, d = 1..D \end{cases} \rightarrow \quad Al = u$$

The solution is achieved by Weighted least squares (WLS) method $\hat{l} = (A^T W A)^{-1} A^T W u$

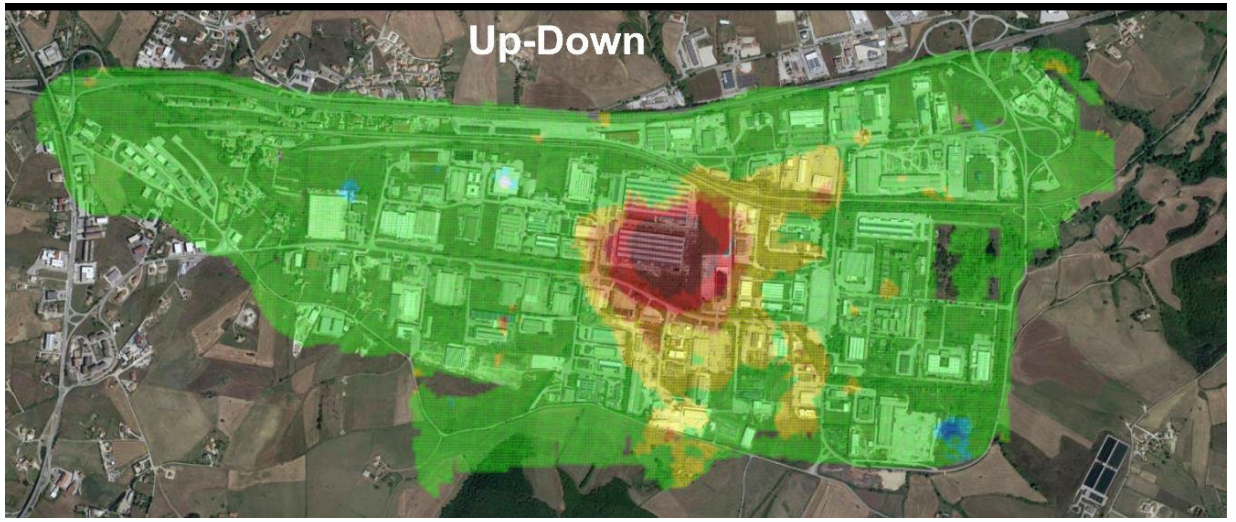
A decay constant of used distance is introduced to weigh the contribution that each PS measurement brings to the 3D components estimate according to the exponential formula

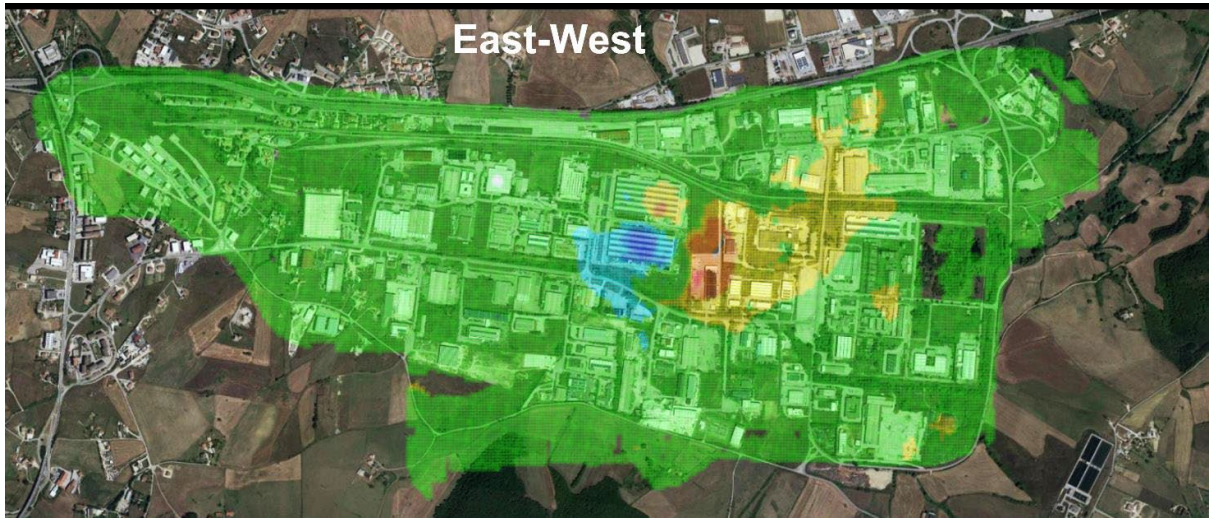
where $f(d_i) = e^{-\frac{d_i}{d_0}}$

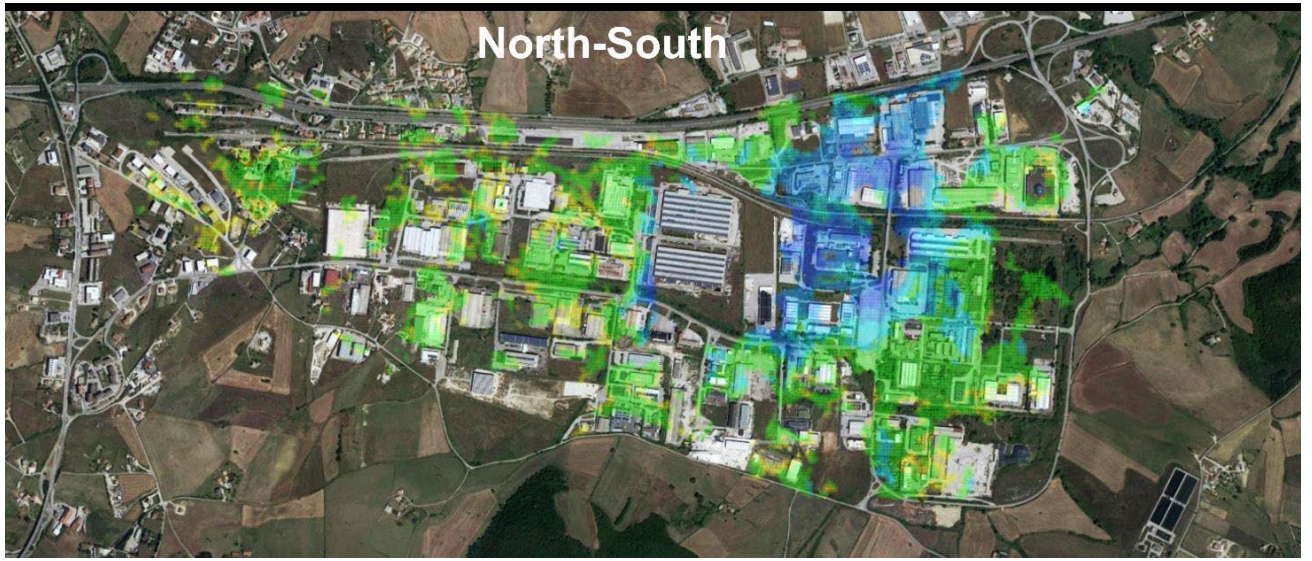
- di is the distance between the PS measurement PSi and Xp is the point where the estimate is determined
- d0 is the location



MUSAR: Multi-sensor InSAR data fusion







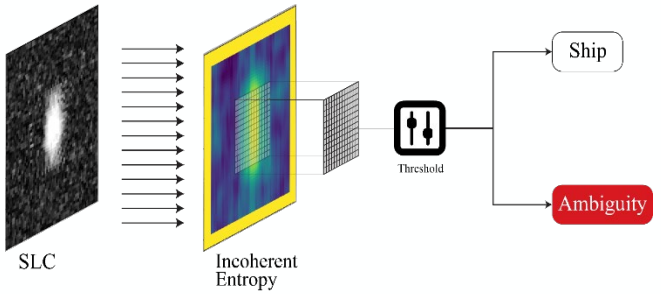
Estimation of 3D displacement components achieved through data fusion of COSMO-SkyMed and Sentinel-1 Persistent Scatterers in a built-up area in Tito Scalo, Potenza (Italy) affected by subsidence. (**image courtesy NHAZCA S.r.l., MUSAR project**).

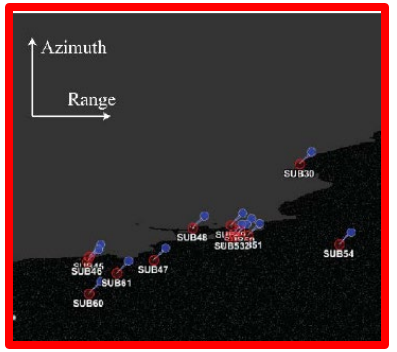
NHAZCA
NATURAL HAZARDS CONTROL AND ASSESSMENT

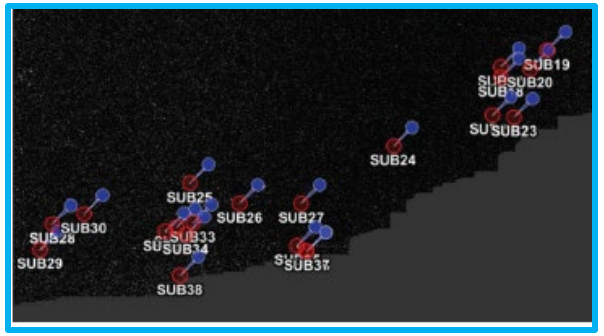
More details in the poster by Belcecchi et al. @ FRINGE 2023

COAST: SAR-based ship detection

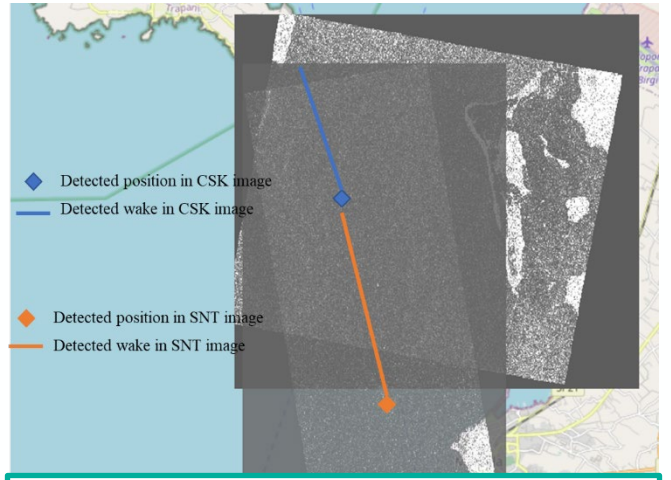
- **Partners:** Federico II" Napoli Univ. (UNINA), Euro.Soft srl
- **Objectives:** Improve multi-frequency and multi-polarimetric ship detection algorithms based on target related properties.



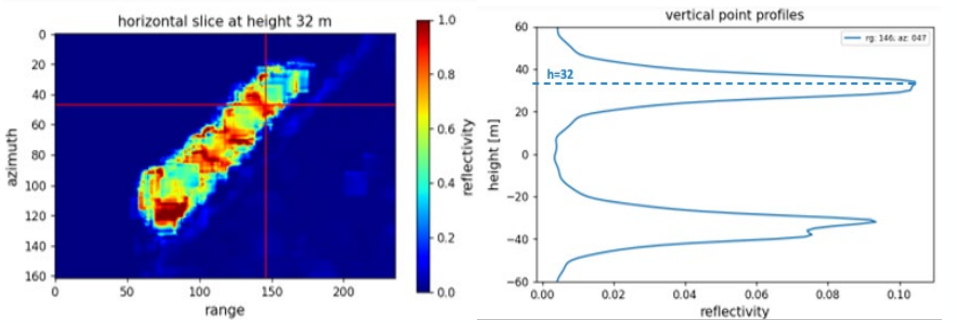




Results on the ship detection pipeline (CFAR approach, Sub-Look Analysis and Incoherent Entropy) applied to CSK (BLUE), SAOCOM (GREEN) and Sentinel-1 (RED) data: red points correspond to identified targets. Product produced from Original SAOCOM Product - ©CONAE – COMISION NACIONAL DE ACTIVIDADES ESPACIALES (2020-2021)



Results of ship-wake detection algorithm based on Radon Trasform, applied to multi-temporal CSK and Sentinel-1 SAR images.

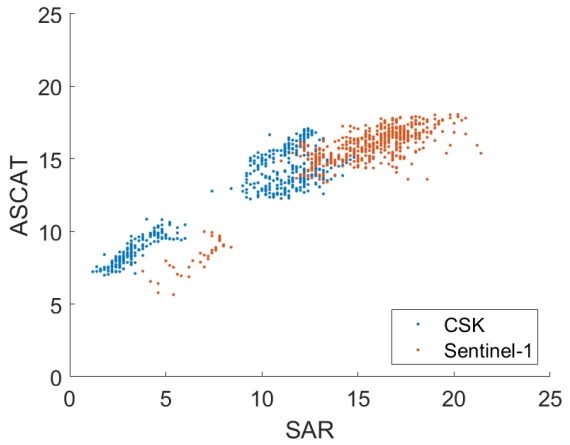


Tomographic profile of Diamond Princess ship, gathere with TomoSAR processing of CSK dataset.

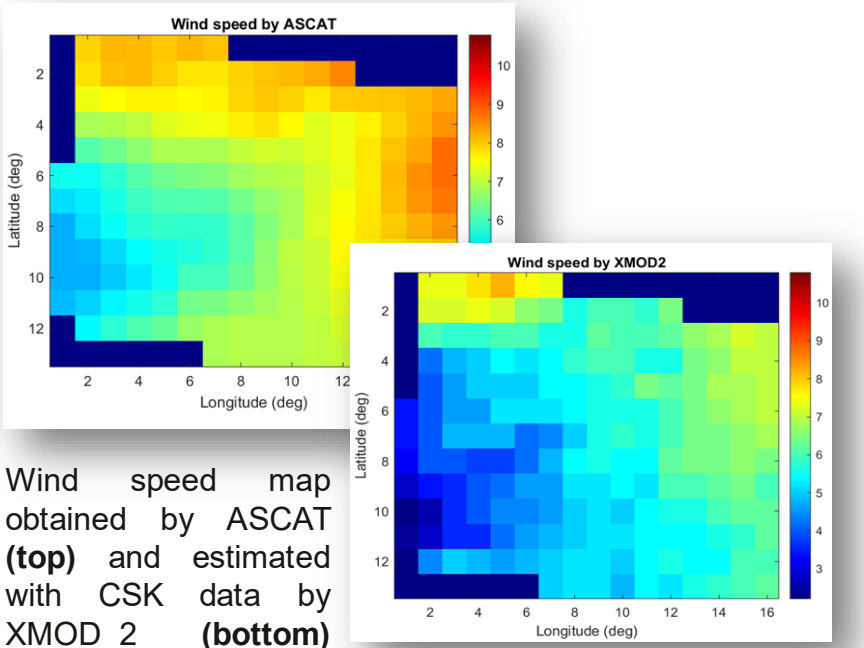
Images courtesy DII-UNINA, COAST project

APPLICAVEMARS: SAR-based wind field estimation

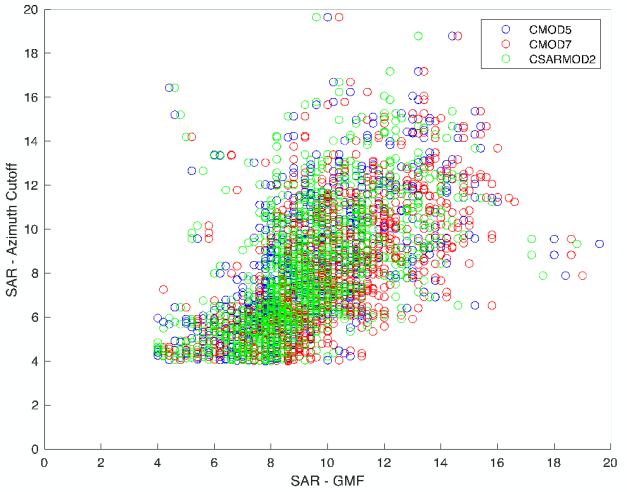
- **Partners:** Parthenope" Napoli Univ. (UNP), CNR-ISP, ICM-CSIC
- **Objectives:** develop, verify and ameliorate GMF algorithms to estimate wind field from SAR imagery at different spectral bands, also improving product validation and cross-comparison phases.



Scatterplot to contrast SAR retrievals (blue and red spots stand for CSK and S1, respectively) with ASCAT reference wind, for dataset collected in North Sea



Wind speed map obtained by ASCAT **(top)** and estimated with CSK data by XMOD_2 **(bottom)** using the ASCAT wind direction



	Azimut Cut-Off		
GMF	CRMSD	BIAS	CORR
CMOD5	1.7799	1.1378	0.5840
CMOD7	1.8073	1.8172	0.5783
CSARMOD2	1.7894	1.1501	0.5691

Scatterplot to contrast S1 winds retrieved using azimuth cut-off with the GMF ones.

Images courtesy Parthenope University, APPLICAVEMARS project

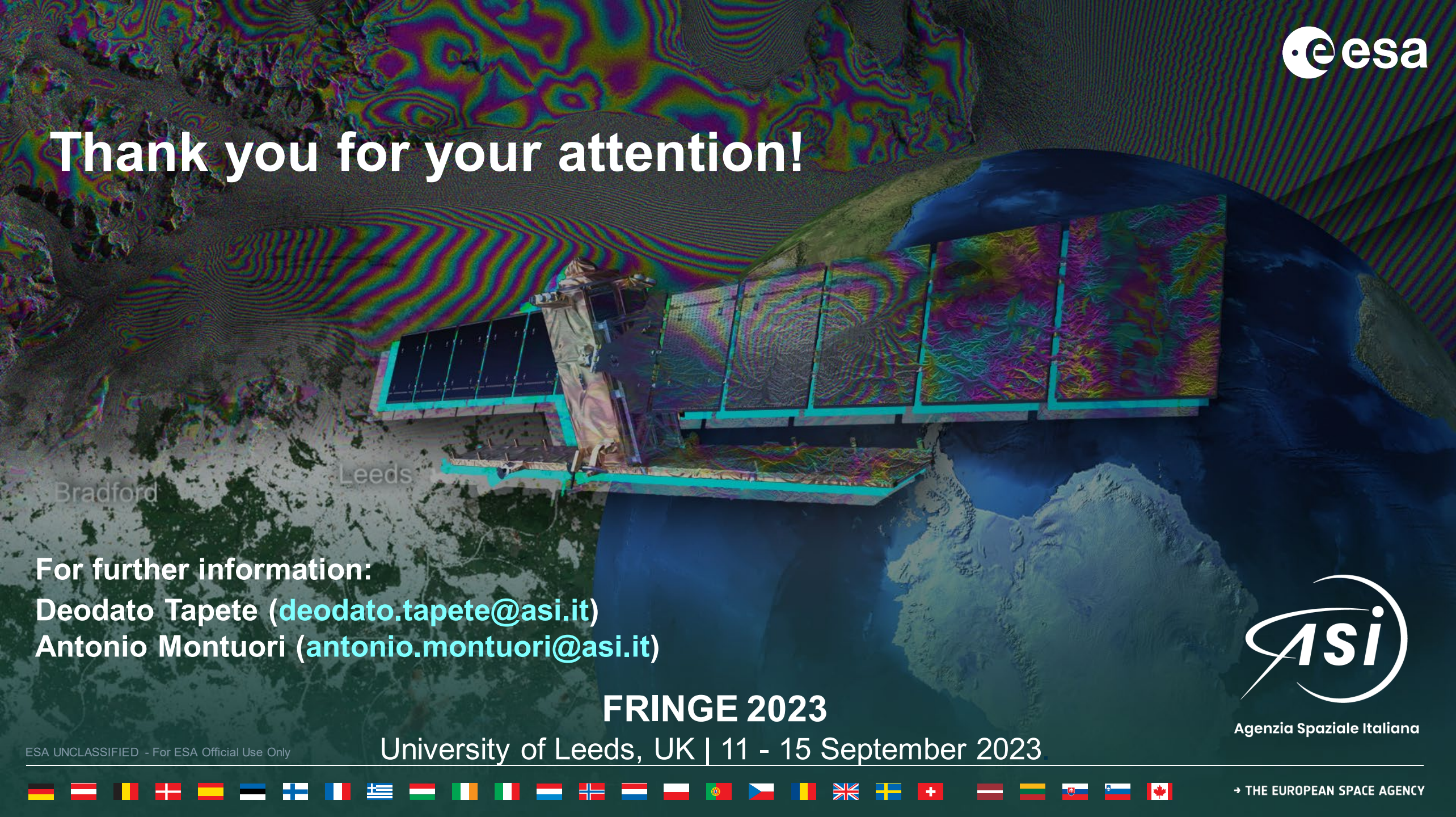
Highlights, conclusions & future perspectives

- The SAR MMF program allowed consortia to develop mature and validated chains for processing **SAOCOM data**, paving the way **towards a more routine and systematic use of these L-band data**, e.g. for civil protection and disaster risk management purposes;
- In the longer-term perspective, the national community will be best placed to exploit L-band SAR data from future satellite missions (e.g. ROSE-L and NISAR), taking benefits of **test-bed and expertise gained** within ASI's SAR MMF program;
- In **agricultural** applications, **ground motion** assessment and **cryosphere**, L-band SAR data proved crucial to retrieve crop/vegetation properties, identify deformation patterns caused and retrieve snow properties;
- Concerning **maritime** applications, ship detection pipelines were successfully assessed in case of visible and non-visible ships, taking benefits of multi-frequency SAR products provided as single and joint acquisitions;
- Concerning **marine** applications, L-, C- and X-band Geophysical Model Functions (GMFs) were properly tested over Sentinel-1, CSK/CSG and SAOCOM data, with improvements obtained at C- and X-band by exploiting wind direction directly from the SAR scene;

Highlights, conclusions & future perspectives

- For purposes of SAR data integration and urban changes analyses, all the above described applications demonstrated that acquisitions collected **at different wavelengths with short temporal time span**, if not **even co-located**, are very advantageous.
- These types of SAR datasets, however, can be achieved **through a coordinated satellite tasking that can be addressed at the space agency's level only**, and making the best out of bilateral cooperation and virtual constellation approaches.
- According to the ASI's roadmap for scientific downstream applications, the outputs of the SAR MMF program will form the **basis/input for proper demonstrators** wherein they can be exploited operationally, to address specific needs expressed by the user community and/or institutional stakeholders
- The SAR MMF acts as a foundational step of the ASI's "Innovation for Downstream Preparation" (**I4DP**)

Thank you for your attention!



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FRINGE 2023
University of Leeds, UK | 11 - 15 September 2023

Agenzia Spaziale Italiana