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Satellite X-band SAR data exploitation trends in the framework of ASI's COSMO-SkyMed Open Call initiative

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Abstract

COSMO-SkyMed (Constellation of Small satellites for Mediterranean basin Observation) is an Italian Earth Observation (EO) and Dual-Use (Civilian and Defense) Space System conceived with the aim to establish a worldwide service providing Synthetic Aperture Radar (SAR) data, products and services compliant with well-established international standards and relevant to a wide range of applications, such as emergency and risk management, scientific and commercial applications and defense Applications. Starting from 2007, the Italian Space Agency (ASI) has promoted the COSMO-SkyMed SAR data exploitation through several initiatives such as "Announcement of Opportunity", "Open Call for Science" and "Open Call for National Small and Medium Enterprises (SMEs)". This paper is focused on the trends and results observed in the context of the "Open Call for Science", an initiative completely addressed to the national and international scientific community since 2015. In particular, in this framework, the observed trend and advances in science and applications of SAR imagery and Interferometric SAR (InSAR) are summarized and assessed, also in light of the scientific evidence published in the recent literature by scientific users of ASI's "Open Call for Science".

Keywords: SAR data exploitation; Earth Observation missions, COSMO-SkyMed, InSAR.

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1. Introduction

In the last decades the Italian Space Agency (ASI, *Agenzia Spaziale Italiana*) invested significant effort in the Earth Observation (EO) field by means of the COSMO-SkyMed Program, based on a radar satellites constellation, and the development of its follow-on, known as COSMO-SkyMed Seconda Generazione (CSG). The COSMO-SkyMed system was commissioned and funded by ASI and the Italian Ministry of Defense (MoD) as well as entirely developed and produced by the national space industry. The aim was to achieve an independent and reliable EO capability operating from space, exploiting the excellent scientific and technological know-how reached by Italy in the field of Synthetic Aperture Radar (SAR) data. This space program is one of the largest investments worldwide in the framework of EO (around 1.2 B€) and still represents the most performing SAR system available if we consider aspects such as revisit time, spatial and temporal resolution.

The first-generation constellation (referred to as CSK) consists of four satellites, launched in the time range 2007-2010 and operating since 2007 [1]. The second-generation constellation CSG consists of two additional satellites joining those of the first generation [2]. They will provide the users with new acquisition modes, improved performances, new operative solutions, and enhanced capability to manage and satisfy heterogeneous and complementary dual use (i.e. Civilian and Defense) requirements, thus ensuring the continuity of the SAR EO operations [2]. The first satellite of the second generation (CSG-1) was launched from Kourou on 18 December 2019 by Arianespace using a Soyuz rocket.

The COSMO-SkyMed mission has been an exceptional tool for observing our planet. More than 10 years of operations constitute a great return of experiences and lesson learned that have been capitalised in defining the new CSG system architecture and operative concepts. With its innovative operational capabilities, CGS will be able to guarantee the continuous monitoring of the Earth's surface, as well as to consolidate and enlarge the Italian leadership on SAR observation from space keeping a strategic prevalence on an increasing market of high technology.

Nomenclature

ASI	Agenzia Spaziale Italiana (Italian Space Agency)
COSMO-SkyMed	Constellation of Small satellites for Mediterranean basin Observation
CSK	COSMO-SkyMed (first generation)
CSG	COSMO-SkyMed di Seconda Generazione (COSMO-SkyMed Second Generation)
EO	Earth Observation
InSAR	Interferometric Synthetic Aperture Radar
MSI-UGS	Multi-Sensor Interfacing UGS
PI	Principal Investigator
SAR	Synthetic Aperture Radar
UGS	User Ground Segment

1.1. COSMO-SkyMed Mission status: first and second generation

The mission objectives of COSMO-SkyMed are related to a space mission with a dual nature (i.e. capable to satisfy civilian and defense customers), able to provide information and services on a worldwide basis for a large number of activities and applications, such as (but not exclusively) risk management applications, cartography and planning applications, agriculture, forest, hydrology, geology, marine domain, archaeology.

As mentioned above, the space segment of CSK consists of four Low Earth Orbit mid-sized satellites, each equipped with a multi-mode high-resolution SAR operating at X-band (3.1 cm wavelength) and fitted with particularly flexible and innovative data acquisition and transmission equipment. The system was completed by dedicated full featured Ground infrastructures to manage the constellation and ensure ad-hoc services for collection, archiving and distribution of acquired remote sensing data. This infrastructure has been upgraded and improved in the framework of the CSG programme, through the realization of a specific module of User Ground Segment (UGS), called Multi-Sensor Interfacing UGS (MSI-UGS), devoted to provide multi-mission/multi-sensor upstream services to the final users. The multi-mission/multi-sensor feature is the capability to task and manage several sensors/missions in an integrated ground segment environment [3]. This allows:

(i) minimizing the operational effort, through the reduction and optimization of logistics and operational tasks/personnel;

(ii) optimizing the overall image data collection process, through the effective and automatic coordination of the different sensors/missions tasking (e.g. managing multi-mission/multi-sensor programming order for optical and/or SAR products).

The COSMO-SkyMed constellation started operations in September 2008, with the deployment of the first two satellites qualified in orbit. The deployment of the complete constellation onto operations, with four satellites qualified in orbit, was completed in January 2011. Currently, all the first-generation satellites completed their nominal operational life (5.25 years), but the constellation is still operating and provides images with the required image quality (the nominal End of Life due to the "consumables", i.e. fuel sizing, batteries life etc, is 7 years). Starting from 2017, CSK3 and CSK4 satellites are operating in full gyro-less mode.

In nominal conditions, the four satellites are in the same orbital plane and currently positioned as depicted in the following Fig.1:

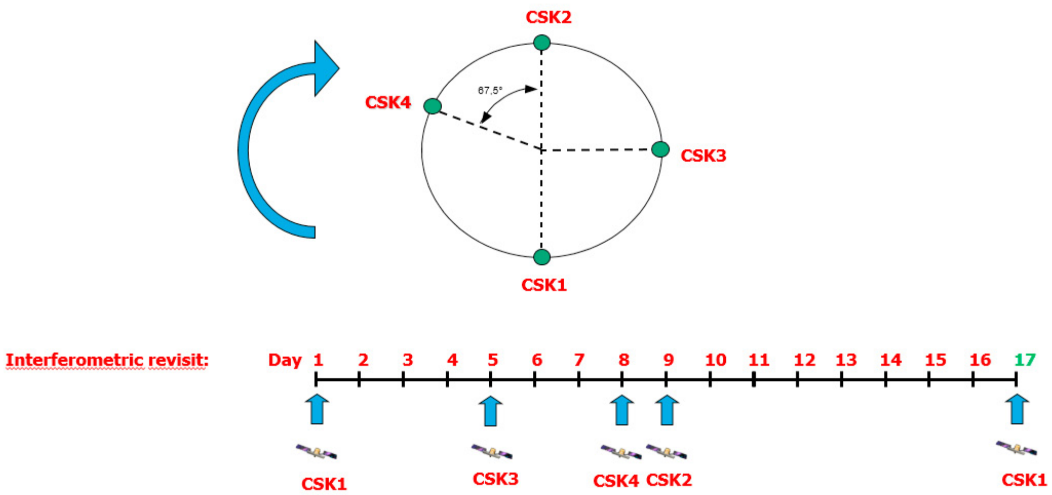

Fig. 1. Current orbital configuration (CSK4 and CSK3 were moved in June 2019), courtesy of e-Geos

The nominal (full sized) constellation orbiting configuration is conceived to achieve the best compromise among cost and performance, providing a global Earth access at constellation level of few hours, with at least two daily passages over the same target on the Earth under different observing conditions (incidence angle). Furthermore, in mid-2019 it has been decided to put satellites CSK2 and CSK4 at 67.5° each other in order to reach a "one day interferometry" configuration with minimal impacts on revisit time. This allows actuating, whenever necessary, an interferometry mission at one day (so called "Tandem Like" configuration).

In the last years some developments/evolutions have been introduced in order to guarantee the competitiveness of the system in a global context, for example changing the Routine Chronology from H24 to H12. COSMO-SkyMed has three different system operative modes: a) Routine; b) Crisis; c) Very urgent. In the first mode (routine) the user requests are planned and sent to the satellite constellation once a day, whereas in the crisis mode this operation is done twice a day. The third mode (very urgent) is asynchronous, allowing an acquisition request to be satisfied with the minimum possible latency (few hours). In 2015 the routine chronology was modified from H24 to H12 (twice a day) in order to guarantee better performance for emergency response. Costs were borne by e-Geos which, in this scenario, is the company (20% ASI, 80% Telespazio) that has the exclusive rights to sell COSMO-SkyMed data (from both first and second generations) to the commercial community.

For the second generation CSG, the satellites are improved versions of the original design, representing the state-of-the-art of technologies and engineering solutions [4]. The system will set a new performance standard for spaceborne radar observation systems, in terms of precision, image quality and flexible user services. CSG improvements are: enhanced geometric resolution, multi-polarization acquisitions, enhanced geolocation accuracy, extended lifetime, higher agility of the platform, higher operative profiles, wider portfolio of expandability options, easier interoperability with other systems. A comparison between satellites of first and second generations is summarized in Table 1.

Table 1. Technical and operational features of CSK vs CSG satellites.

	CSK	CSG
Number of satellites	4	2
Projected satellite life-time at full performance	5 years + 2 prolonged	7 years + 2 prolonged
Max SAR bandwidth	400 MHz	1200 MHz
Daily imaging capacity per satellite	450 (single pol)	520 (dual pol)
Downlink data rate	320 Mbps	1400 Mpbs
On-board data storage	320 Gbits	1200 Gbits
Peak power consumption during acquisition	12 kW	20 kW
Satellite mass	1860 kg	2240 kg
Routine operations	24 hours (civilian 12 hours from 2015)	12 hours
Satellite manoeuvres	Reaction wheels	Contro Moment Gyro
Time to rotate from Right to Left looking	6 min	3 min

Furthermore, CSG has additional capabilities, such as non-standard acquisition modes (operational and experimental ones). The system is further designed to provide the maximum operational capabilities through a specific approach to manage dynamically the system resources. In addition, a new planner tool has been developed to better solve system/user conflicts. Finally, a unique integrated ground system, already deployed and operational (since 2017), that will compound the features of first- and second-generation systems.

CSG1 satellite is planned to be positioned with 45° phasing from CSK-1 (Fig. 2). Currently operations are ongoing to put this satellite in its nominal configuration, and CSG data access for the users community is expected to be opened within the end of 2020. CSG satellites will provide the mission operational continuity at least until 2028.

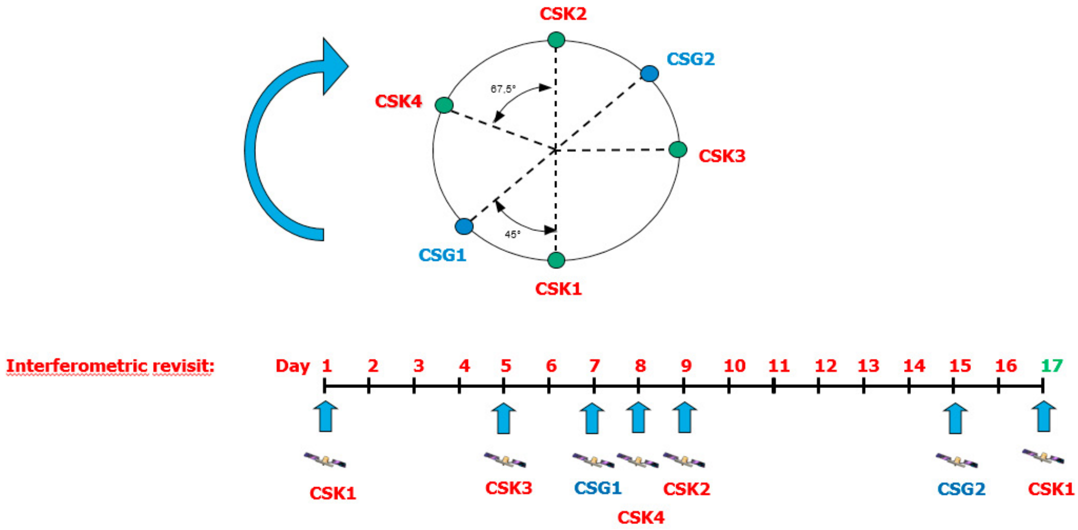

Fig. 2. CSK+CSG orbital configuration and interferometric revisit time (courtesy of e-Geos)

2. COSMO-SkyMed data access, strategy of exploitation and current initiatives for scientific EO community

Due to the dual use needs, COSMO-SkyMed data access is regulated by means of an appropriate and well-defined Data Policy, currently under revision. Users are classified mainly in two separate classes: Civilian and Defense Users. In the Dual-Use resources sharing context, 75% of the system resources is available for ASI, whereas the remaining 25% is devoted to Defense users and their international partners. In the Civilian domain, users can be Institutional or Commercial Users. The institutional users are “entities” that pursue institutional, scientific (no profit oriented) and public objectives. They are directly managed and coordinated by ASI, whereas the commercial users can access the system through the commercial provider e-Geos. For what concerns the utilization strategy, it is possible to schematize the agreements in the following way:

- ASI owner projects (including specific acquisition handbooks);
- National and International projects based on “On Demand” requests;
- International Cooperation.

As the owner of the system, ASI has activated several projects aiming at the exploitation of CSK data/products by the Institutional Users, at both National and International levels, which can be summarized as follows [5]:

- Foreground Mission (Map Italy project);
- Background Mission, which includes different acquisition handbooks;
- Joint and Open Call initiatives.

In this paper the focus is addressed to analyse trends and results obtained in the context of the COSMO-SkyMed “Open Call for Science”, published in February 2015. The paper further considers the previous experiences and lessons learnt within the context of COSMO-SkyMed data exploitation such as the first Announcement of Opportunity started in 2007, with 140 International projects accessing COSMO-SkyMed data free of charge and 27 national projects funded by ASI. An overview of previous ASI initiatives is given in [6]. The mentioned call is focused on the exploitation of COSMO-SkyMed data for civil applications and is addressed to the National and International Scientific Community. The investigators are invited to submit original scientific proposals, ensuring for each project a maximum of 100 COSMO-SkyMed standard scenes free of charge (80% from data archive and maximum 20% from new acquisition). At the end of 2019, about 160 new projects coming from the scientific community have been accepted, involving principal investigators (PIs) from different nationalities, with a strong participation from the National community (Italian PIs represent about 51% of the total).

In the framework of the COSMO-SkyMed "Open Call for Science", the Primary Applications Domain shows "Risk Management and Environmental Safety" as the priority objective with 45% (Fig. 3). A number of projects are closely connected with Disaster Risk Reduction (DRR) in order to reduce natural disasters impact, with a focus over European territories. In this framework, thanks to its features, COSMO-SkyMed plays a key role in emergency response activities, being a largely exploited SAR mission during disaster events for damage assessment and support to logistic. The system is also able to monitor efficiently the different phases of crisis: early warning, recovery operations and post-crisis, representing a step forward towards a new approach for managing and limiting the effects of natural/anthropic disasters.

The most exploited sensor mode by scientific community is the StripMap HIMAGE one (see [1] for technical details), which represents the best compromise between spatial resolution (3m x 3m) and swath (40 km^2) in a single acquired frame. Furthermore, the scientific community prefers using an appropriate processing level (1A-SCS) useful for interferometry applications that could lead to a better understanding of EO phenomena.

ASI keeps maintaining its commitment in support of the scientific community and strongly encourages investigators to apply to the ongoing open call at www.asi.it/ (section CALLS and OPPORTUNITIES → CALLS → Open Call for Science).

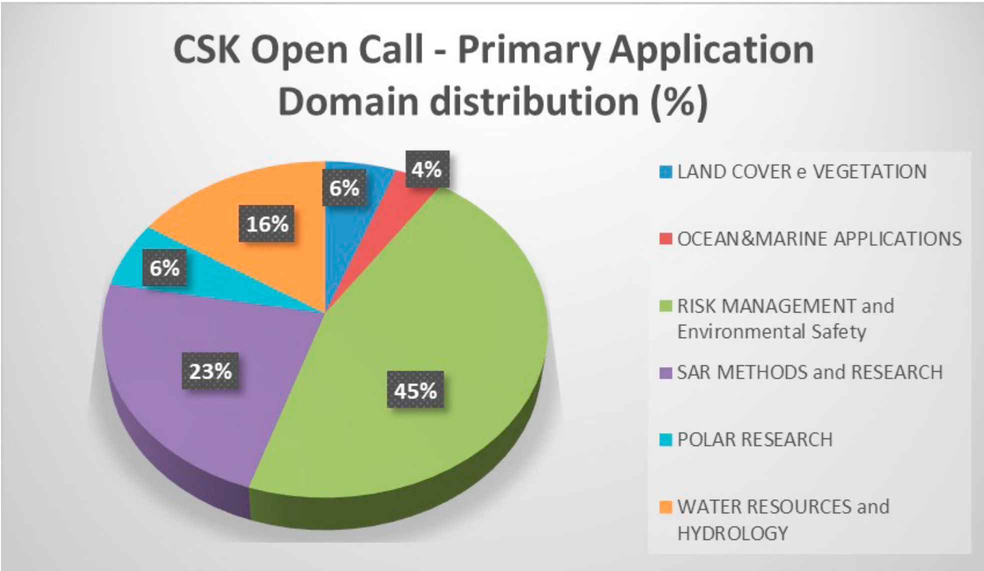

Fig. 3. Distribution of Primary application domains– ASI's COSMO-SkyMed Open Call initiative

3. State-of-the-art on COSMO-SkyMed applications in the framework of the Open Call

In the context of the current initiatives and observed trends (see section 2), it is worth noting that InSAR applications are increasingly moving towards integration of multi-sensor and multi-band SAR data, geological modelling, digital elevation model generation, and combination of different viewing geometries, to better constrain the 3D deformation field of environmental and human-induced hazard processes.

In this context, the COSMO-SkyMed constellation is now particularly regarded by the users of ASI's Open Call as a source of high spatial resolution X-band SAR data complementing other SAR sensors, above all the medium resolution Copernicus Sentinel-1 C-band SAR datasets. A recent example of advanced integration approaches exploiting COSMO-SkyMed time series is demonstrated by Ezquerro *et al.* (2020) [7] with regard to groundwater resources management in anthropogenic environments. This is an application with social and economic impacts, where understanding the behaviour of aquifers is crucial to mitigate adverse consequences of groundwater overexploitation, as well as to use natural resources more sustainably. The 2D decomposition of InSAR displacements from COSMO-SkyMed and Sentinel-1 satellites over the Alto Guadalentín Basin in Spain allowed the detection of not only vertical displacement rates exceeding 10 cm/year, but also ~1.5 cm/year horizontal deformation towards the basin centre. The estimates of the surface deformation induced by groundwater pumping were then integrated with groundwater flow and deformation models to improve the aquifer-systems sustainable management.

By focusing on the SAR data processing approaches, there is a significant methodological push for state-of-the-art multi-temporal differential InSAR (DInSAR) techniques, either Small Baseline Subset (SBAS) or Persistent Scatterer Interferometry (PSI), to further enhance their performances in order to extract a greater number of surface deformation estimates from the SAR datasets, thus achieving a denser spatial coverage of the study area and a better characterization of the deformation field (Minh *et al.*, 2020) [8]. One of these novel approaches is the so-called Distributed Scatterer (DS) InSAR, such as the SqueeSAR algorithm developed by Ferretti *et al.* (2011) [9]. Differently from methods that exploit dominant scatterers exhibiting high phase stability over a time interval, DS approaches aim to retrieve the phase history from many small targets distributed over natural land covers (e.g., bare land, debris, desert, low vegetated areas) that share the same statistically homogeneous behaviour (Minh *et al.*, 2020) [8]. The challenge with DS is that their average temporal coherence is typically low, and therefore the resulting signal-to-noise ratio is low. Jiang and Monti Guarnieri (2019) [10] developed a methodology to improve the estimation accuracy of DS interferometry. In particular, the authors processed a 1-year long COSMO-SkyMed data time series collected over Yongshan town in China and accessed through the Open Call, compared the DInSAR results with those obtained with Sentinel-1 data, and evaluated the influence of coherence estimation on DS InSAR time-series analysis.

One of the emerging research applications concerning the scientific use of COSMO-SkyMed data is related to the generation of either Digital Elevation or Surface Models (DEM and DSM, respectively) for environmental studies. This appears to be particularly relevant, given that in the scientific literature COSMO-SkyMed is much more used for two-pass and multi-temporal DInSAR approaches for surface deformation analysis than for DEM generation. Guimarães *et al.* (2018) [11] have recently evaluated the vertical accuracy of DSMs under Amazon coastal environments generated from COSMO-SkyMed and TerraSAR-X StripMap datasets, using both Toutin's and SARscape's radargrammetric models together with the minimum and recommended number of the stereo ground control points (SGCPs) for each approach. In both cases, radargrammetric DSMs of the flat relief of the Amazon coastal environment were produced with an almost continuous surface, although the acquisitions occurred during the rainy season and high amplitude of tides, with low to moderate incidence angles (from 24° to 51°) and the use of a reduced number of stereo ground control points. The vertical accuracy was similar for COSMO-SkyMed and TerraSAR-X, with the Root Mean Square Error (RMSE) shared intervals between 4.34–7.76 m and 4.75–5.04 m, respectively. The results demonstrate the potential to monitor the topography at a detailed level of the spatial and temporal scales. Using these datasets, the research team was also able to map the Amazon coast at detailed cartographic scale (Guimarães *et al.*, 2020) [12].

4. Conclusions

CSK has pioneered the operational use of a spaceborne SAR constellation for Earth Observation, proving positive results and a strong heritage for more than 10 years since the launch of the first satellite until the current deployed configuration of four satellites. In the coming years, CSG will follow its track joining CSK satellites, by providing operative continuity on dual-use services with much higher performances through key technology advances and an innovative system design. The principal aim of such advances is to enlarge the range of SAR imagery applications for a wider End Users community while multiplying the efficiency and the versatility of the provided services, through the key system elements that will allow achieving such an ambitious goal.

Since 2008, ASI has strongly supported the exploitation of COSMO-SkyMed data by scientific community through successful projects and agreements. So far, thanks to initiatives such as COSMO-SkyMed Open Call for Science, several thousands of CSK products have been distributed free of charge improving the comprehension of Earth Observation phenomena (e.g. geology, hydrology, biology, oceanology, climatology). From an application point of view, a consolidating trend is found in "Risk Management and Environmental Safety". This evidence further corroborates the impact of X-band SAR data exploitation towards the reduction and prevention of natural and human-made disasters. On the other side, the scientific community is expanding the realm of scientific applications in environmental sciences, geomorphology and improved techniques of radar signal processing.

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References

[1] C. Fiorentino, M. Virelli, M.L. Battagliere, F. Caltagirone, F. G. De Luca, A. Coletta, (2019) "COSMO-SkyMed Mission and Products Description", ASI document, ww.asi.it.

[2] P. Sacco, M.L. Battagliere, M.G. Daraio, M. Virelli, F. Covello, A. Coletta "From COSMO-SkyMed to COSMO Seconda Generazione: evolutions and perspectives", Proceedings of 65th International Astronautical Congress, 29 September–3 October 2014, Toronto, Canada.

[3] C. Fiorentino, S. Serva, M. L. Battagliere, F. Caltagirone, A. Coletta, L. Fasano, S. Mari, M. Porfilio and F. G. De Luca, "International Cooperation based on COSMO-SkyMed System", Proceedings of 67th International Astronautical Congress (IAC 2016), Guadalajara, Mexico, 26-30 September 2016.

[4] E. Scorzafava and al., "COSMO SG, Spacecraft design and technological challenge", Proceedings of European Conference of Synthetic Aperture radar (EUSAR), Berlin, Germany, June 2014.

[5] M. L. Battagliere, M. Virelli, F. Lenti and A. Coletta, "COSMO-SkyMed data exploitation: global trend, perspectives and lessons learnt", Proceedings of 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.

[6] M. L. Battagliere, L. Dini, M. G. Daraio, P. Sacco, M. Virelli, O. Piperno, A. Coletta, "COSMO-SkyMed Open Call: an opportunity for the international scientific community and National SMEs", ESA LPS 2016, Praga, Repubblica ceca, 9-13 Maggio 2016.

[7] P. Ezquerro, R. Tomás, M. Béjar-Pizarro, J.A. Fernández-Merodo, C. Guardiola-Albert, A. Staller, J.A. Sánchez-Sobrino, G. Herrera (2020) Improving multi-technique monitoring using Sentinel-1 and Cosmo-SkyMed data and upgrading groundwater model capabilities. Science of The Total Environment, 703, 134757, https://doi.org/10.1016/j.scitotenv.2019.134757.

[8] Minh, D.H.T.; Hanssen, R.; Rocca, F. 2020. Radar Interferometry: 20 Years of Development in Time Series Techniques and Future Perspectives. Remote Sens., 12, 1364.

[9] A. Ferretti; A. Fumagalli; F. Novali; C. Prati; F. Rocca; A. Rucci 2011. A New Algorithm for Processing Interferometric Data-Stacks: SqueeSAR. IEEE Transactions on Geoscience and Remote Sensing, 49, 9, 3460–3470, doi: 10.1109/TGRS.2011.2124465

[10] Jiang M. & Monti Guarnieri A (2019). Distributed Scatterer Interferometry With the Refinement of Spatiotemporal Coherence. IEEE Transactions on Geoscience and Remote Sensing, doi:10.1109/TGRS.2019.2960007

[11] U. S. Guimarães, I. da Silva Narvaes, M. de Lourdes Bueno Trindade Galo, A. de Queiroz da Silva, P. de Oliveira Camargo (2018) Radargrammetric approaches to the flat relief of the amazon coast using COSMO-SkyMed and TerraSAR-X datasets. ISPRS Journal of Photogrammetry and Remote Sensing, 145, Part B, 284-296, doi: j.isprsjprs.2018.09.001.

[12] U. S. Guimarães, M. de Lourdes Bueno Trindade Galo, I. da Silva Narvaes, A. de Queiroz da Silva (2020) Cosmo-SkyMed and TerraSAR-X datasets for geomorphological mapping in the eastern of Marajó Island, Amazon coast. Geomorphology, 350, 106934. doi: j.geomorph.2019.106934.