

SARSIMHT-NG CAMPAIGN OVER SOUTHERN ITALY FOR INVESTIGATING SUB-DAILY WATER PROCESSES

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ABSTRACT

This paper reports on the European Space Agency (ESA) SARSimHT-NG experiment conducted in 2022 over a well-researched location in southern Italy. The experiment involved extensive ground data gathering coordinated with the German Aerospace Center's (DLR) F-SAR airborne acquisitions in C- and L-bands. The campaign goal was to test the geostationary Synthetic Aperture Radar (GeoSAR) system measurement concept, developed for the Hydroterra mission proposal submitted to the ESA Earth Explorer 10 call and studied in phase 0. The C-band system hyper-temporal feature is instrumental in investigating the water cycle rapid processes. The experiment also investigated the possible synergy between GeoSAR systems and other Low Earth Orbit (LEO) satellite missions, namely Sentinel-1 Next Generation (NG) and the Radar Observation System for Europe in L-band (ROSE-L). The comprehensive soil and vegetation data that were gathered, together with the short-revisit multi-temporal fully polarimetric L- and C-band SAR data, are described in the paper. Insights into the retrieval of the surface dynamics of the water cycle are also provided.

Index Terms— Hydroterra, ROSE-L, Sentinel-1 NG, irrigation, sub-daily water cycle

1. INTRODUCTION

In the last decades, huge progress has been made to measure, by Earth Observation techniques, water cycle variables interconnected in the Earth's energy and water circulation, such as precipitation, evapotranspiration and soil moisture [1]. However, understanding of rapid, fine-scale land processes, particularly those on sub-daily scales and at an extent of km, such as soil and vegetation water content

changes during the day, especially in hot, dry regions, are still poorly understood [2].

To fulfil these scientific needs, the Hydroterra mission was proposed as the European Space Agency (ESA) Earth Explorer 10 mission and was studied as a candidate mission in phase 0 [3]. The mission concept consisted of placing a C-band Synthetic Aperture Radar (SAR) system into a geosynchronous orbit, providing a permanent view of Europe and Africa. The science objectives, among others, were to increase the prediction capability of intense rainfall and related flooding and landslides and to improve the understanding of the diurnal water cycle.

In this context, the "Simulation of Hydroterra SAR System Performance in the Mediterranean and the Alps Based on Experimental Airborne SAR Data" (SARSimHT-NG) airborne campaign was performed in the Apulian experimental site (southern Italy) in April and June 2022 to support the Hydroterra mission scientific objectives. Short-revisit multi-temporal fully polarimetric L- and C-band Synthetic Aperture Radar (SAR) data were acquired by the German Aerospace Center (DLR)'s F-SAR, while intensive ground data collection over irrigated and non-irrigated fields was gathered.

The SARSimHT-NG data set also allows investigation of the capability of a dual-frequency SAR system for deriving surface soil moisture (SSM) in the Mediterranean region in view of the upcoming multi-frequency spaceborne SAR system, ROSE-L and Sentinel-1 Next Generation (NG) [4].

The objective of this paper is to describe the fully polarimetric, multi-frequency SAR data acquired during the airborne campaigns and the in situ observation strategy, and to present and discuss the main results of the data analysis.

2. EXPERIMENTAL SITE

The Apulian Tavoliere is the second largest plain in Italy. It stretches on ~4000 km² in the Apulian region (Figure 1). The plain is bounded in the North by Gargano and in the West by the Daunia Mountains and is located in a steppe (Bsk) climate zone according to the Köppen-Geiger 2018 classification (<https://www.gloh2o.org/koppen>). Winter seasons enjoy mild temperatures rarely dropping below 0°C, while summer temperatures can exceed 40°C. Annual rainfall is approximately 530 mm and is mainly concentrated in the autumn months. The rainiest months are October and November, while the dry period is from May to September. A large part of the area is served by an irrigation consortium (Consorzio per la Bonifica della Capitanata) which distributes on-demand irrigation water to the farms.

Two farms were selected over the area. Figure 1 shows the study areas, which are the private agricultural farm (Az. F.lli Caione) marked by the green contour and the CREA's experimental farm (Manfredini-Menichella farm) marked by the orange contour, both located near the Foggia town. Over the Apulian Tavoliere, the main winter crop is durum wheat. It is a rain-fed crop usually sown in December and harvested in mid-June. Spring-summer crops, e.g., tomato, maize, sunflower, and quinoa, are irrigated. They are sown between April and May and are usually harvested in August. Both farms were equipped with irrigation infrastructures. At the farms, soils have a clay loam texture.

3. EXPERIMENTAL DATA

Two experimental campaigns on April, 28-29, and June, 15-16 were organized and soil and vegetation measurements were taken during the DLR's F-SAR flights in the morning and the afternoon on each day.

3.1. Airborne SAR measurements

The first experiment simulating the Hydroterra acquisition concept was carried out in Germany in 2019 [5]. In 2022, for the Italian experiment, a similar acquisition scheme was adopted. Measurements were performed with DLR's airborne radar system F-SAR [6], operated in a 4-channel, dual-frequency, C- (5.3 GHz) and L-band (1.325 GHz), fully polarimetric mode. The study area was illuminated from the west; the off-nadir angle ranges approximately from 23° to 58°. The F-SAR radar was calibrated before and after each campaign.

Four F-SAR overflights during the campaign in April and June were operated. For three of them, a stack of 12 stripmap SAR data sets was acquired with a zero-meter spatial baseline and an approximately 10-minute temporal baseline. The fourth flight was performed as merely an add-on, i.e., its acquisitions (4-5 stripmaps) were not used for Hydroterra simulation. For each campaign, the temporal distance between the flights was: 5 hours between the first and second

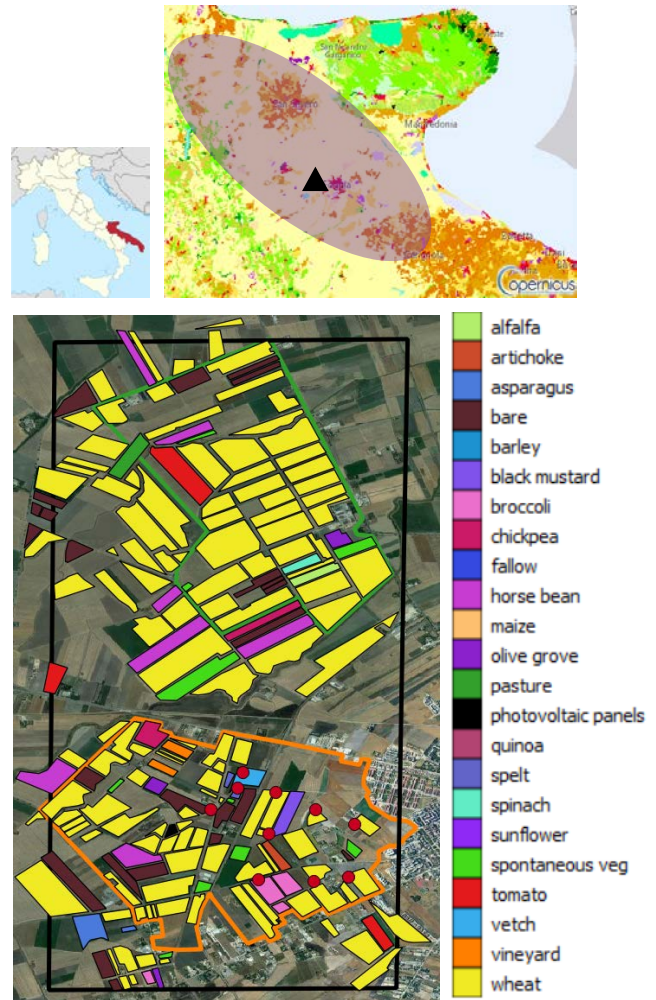


Figure 1. Upper panel: Apulian Tavoliere plain (shaded ellipsis) in the Apulia region (red region) and the test site location (black triangle) over the CORINE Land Cover 2018. Lower panel: area of interest (black rectangle) and 2022 April land use map. The legend reports the colours of the identified crop types at the Caione's (green contour) and CREA's (orange contour) farms. The red points indicate the locations of permanent ground stations.

flights, 24 hours between the first and the third, and 19 hours between the second and the third. It is worth noting that, during the second mission in June, a 20-minute time gap was present in each stack due to hardware dropouts in the data recorder. Furthermore, only 11 stripmaps were acquired for the first flight of June.

For each campaign and frequency, a master acquisition was identified whose geometry serves as a reference for stack co-registration. After SAR data focusing, four calibrated Single Look Complex (SLC) stacks, already co-registered for SAR interferometry, are available. At C-band, the resolutions are 50 cm (30 cm pixel size) in slant range and 50 cm (20 cm pixel size) in azimuth. The two interferometric stacks at C-band were used to simulate Hydroterra acquisitions using the processing described in [5]. At L-band, the resolutions are

130 cm (60 cm pixel size) in slant range and 60 cm (40 cm pixel size) in azimuth.

The acquired data sets were further processed. All SLC data were detected, multi-looked (2x5 rg x az), and geocoded to map geometry at 1 m pixel size. A further boxcar filtering 3x3 was applied. The geocoded products have a resolution of ~3m at C- and ~7m at L-band.

For each campaign, interferometric coherence and phase of all acquisitions were computed with respect to the acquisition of the first pass. Coherence was estimated using a Gaussian window of kernel size 21x21 with SIGMA parameter 5x5, whereas phase by an 11x11 interferogram multi-lookup. Both products were geocoded to the same map geometry of the backscatter intensity.

3.2. In situ measurements

During the ground campaigns in April (and June), two fields at Caione’s farm and two (three) fields at CREA’s farm were selected for intensive monitoring during the F-SAR flights. The fields were bare or cultivated with durum wheat in April, and with maize, sunflower, alfalfa, and quinoa in June. More than 3000 soil measurements were collected at gridded sample points by portable impedance and TDR probes. In April and June, three ground stations were deployed over the monitored fields at CREA’s and Caione’s farms. Each station measured soil moisture content and temperature at two depths (i.e. 5 cm and 20 cm) by capacitance sensors. Site-specific calibration of both portable and temporary soil moisture sensors was carried out by thermos-gravimetric method. Besides, at CREA’s farm, CNR-IREA has been running a hydrologic network, since July 2017 (red points in Figure 1). The network consists of 10 ground stations. Each station measures soil moisture content at 4 depths (i.e., 2.5-10 cm and 20-40 cm) by calibrated capacitance sensors.

Fresh vegetation biomass was also collected via destructive sampling at selected grid points and, then, vegetation water content was calculated after drying out in the oven. Capacitance sensors were also used to detect the presence and duration of rain/irrigation interception or dew on the leaves. Information about the phenological stage was also gathered.

Selected fields were equipped with irrigation systems, i.e., mobile boom or drip irrigation. They were divided in stripes irrigated on different dates to produce a sufficient soil moisture contrast between irrigated and non-irrigated areas during the F-SAR overflights. The amount of water supplied and the starting and end times of the irrigation were also recorded. As an example, Figure 2 shows the irrigation strategy on the CREA’s durum wheat field in April. The field was irrigated along four parallel stripes on different days as reported in Figure 2. The irrigation scheduling was on April, 26 (two days before the first overflight), on April, 27 and on April, 28 and 29 (during the campaign). The irrigation started from the inner part of the field toward the street, as indicated



Figure 2. Upper panel: CREA’s durum wheat field that was irrigated by a mobile boom system. Lower panel: stripes irrigated on different dates at the durum wheat field. The locations of the ground stations are marked by black points. The black arrow indicates the moving direction of the irrigation system. The image in the background is the Sentinel-2 RGB image on April 27, 2022.

by the black arrow. The mobile boom system covered a length of 120 m, shorter than the entire stripes.

4. SUB-DAILY DATA ANALYSIS

The analysis concerns the stack of multi-temporal i) stripmap C- and L-band SAR images acquired during the F-SAR overflights and ii) the simulated Hydroterra products.

An analysis to ascertain the sensitivity of polarimetric L- and C-band SAR data to SSM underneath different crops is carried out using the airborne data set with the support of the in situ measurements. The specific contribution of multi-frequency SAR data for retrieving SSM and disentangling the vegetation effect is assessed as a function of polarization and incidence angle.

Examples of sub-daily C- and L-band SSM maps are derived by using the CNR “Soil MOisture retrieval from multi-temporal SAR data” (SMOSAR) code [7] and/or a

recursive algorithm based on a short-term change detection approach [8]. The rationale of the approaches is that the change in backscatter between two subsequent observations is only a function of soil moisture change, while the other surface parameters are assumed to be constant, as they usually vary at longer temporal scales. The SSM maps are derived both from the stripmap SAR images and the simulated Hydroterra products.

For instance, Figure 3 illustrates how rapid irrigation-induced changes in SSM may affect the SAR coherence and temporal ratio of the L-band VV backscatter computed at a short revisit. The backscatter ratios on April 28 after 11 minutes, 2 hours, and 5 hours are reported sequentially. The time series of backscatter ratios were able to follow the evolution of the SSM changes underneath the durum wheat along the stripe irrigated from 9:00 to 15:00 on April 28. Additionally, a decrease in coherence to the surrounding area can be also observed over the irrigated stripe.

5. SUMMARY

The SarsimHT-NG campaign was carried out over the Apulian Tavoliere experimental site, in southern Italy in April and June 2022. The collected SAR data include time series of C-band and L-band stripmap images acquired by the DLR's F-SAR every 10 minutes, as well as simulated Hydroterra products. Detailed soil and vegetation measurements were collected to support the interpretations of the agricultural field response to SAR imaging. Short-revisit C- and L-band observation synergy is investigated in the view of ROSE-L, Sentinel-1 NG and GeoSAR missions.

6. ACKNOWLEDGEMENTS

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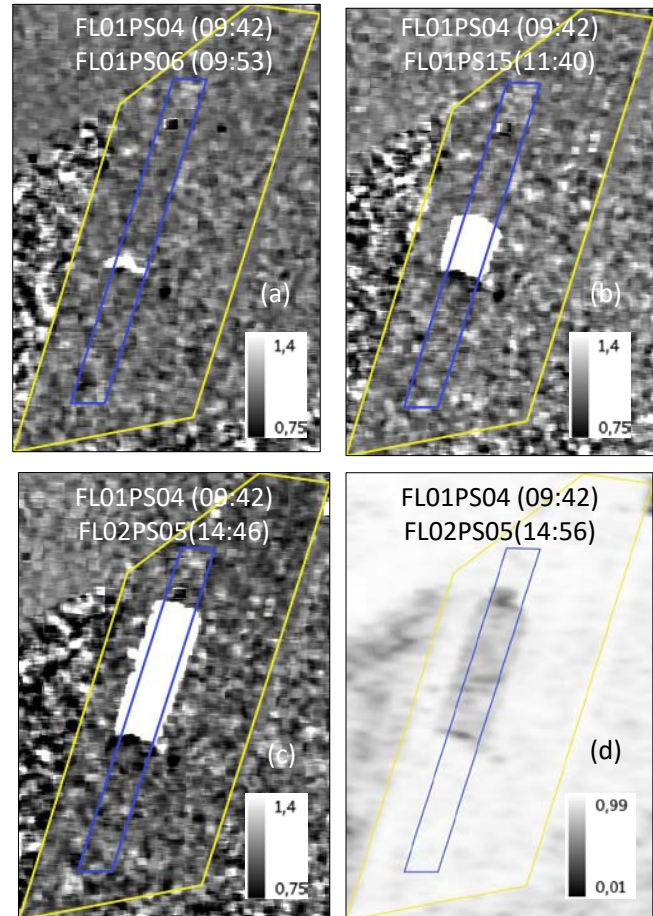


Figure 3. (a) (b) (c) L-band VV intensity ratios between 09:53 and 09:42, 11:40 and 09:42 and 09:42 and 14:56 and 09:42 of the CREA's durum wheat field (yellow border) irrigated along one stripe on April, 28 (d) Coherence between 14:56 and 09:42.

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