Consiglio Nazionale delle Ricerche

Institute for Electromagnetic Sensing of the Environment

IREA for societal challenges

Technologies for Environmental Monitoring Risk Prevention and Healthcare

Edited by Maria Consiglia Rasulo

edizioni
Consiglio Nazionale delle Ricerche

Consiglio Nazionale delle Ricerche

Institute for Electromagnetic Sensing of the Environment

IREA for societal challenges

Technologies for Environmental Monitoring Risk Prevention and Healthcare

---

Edited by Maria Consiglia Rasulo

Consiglio Nazionale delle Ricerche
Institute for Electromagnetic Sensing of the Environment

Piazzale Aldo Moro, 7 - 00185 Roma
ISBN 978-88-8080-670-7 (print edition)
ISBN 978-88-8080-671-4 (electronic edition)
DOI: http://doi.irea.cnr.it/2024REPORTIREA

PREFACE

It is with great pleasure that I present this overview of the ongoing scientific activities of the Institute for Electromagnetic Sensing of the Environment.

This survey was realized to create a streamlined and usable volume, presenting the research activities carried out at IREA with an emphasis on their applications. Public research is increasingly asked to transfer results to civil society and private and public companies, in order to broaden the impact and benefits of knowledge.

Accordingly, in this volume we highlighted the Institute's capability to find solutions to concrete problems for citizens and stressed the impact of IREA's research on everyone's life.

Although we have not focused specifically on the scientific aspects of the IREA research activities, I am confident that this report will allow the reader to appreciate the breadth and depth of our scientific efforts across a broad range of disciplines, ranging from Microwave and Optical Remote Sensing to Electromagnetic Diagnostics, to Bioelectromagnetics, to Geographic Information Systems up to the Public Communication of Science.

Finally, I would like to thank all those who contributed to this effort, with a specific mention to Dr. Maria Consiglia Rasulo for her decisive role in planning, revising and editing.

DIRECTOR

Francesco Soldovieri

Phone +39 081-7620612

soldovieri.f@irea.cnr.it

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

OVERVIEW

IREA PROFILE

The Institute for Electromagnetic Sensing of the Environment (IREA) is one of the Institutes of Excellence of the National Research Council, the largest multidisciplinary research institution in Italy. The research activities aim at developing methodologies and technologies for the acquisition, processing and interpretation of images and data obtained from electromagnetic sensors, operating remotely (satellite, aircraft and drone) or in situ, finalized to environmental and territorial monitoring, non-invasive diagnostics and electromagnetic risk assessment. In addition, methodologies and technologies for the construction of geospatial data infrastructures and biomedical applications of electromagnetic fields are developed. Attention is also dedicated to investigations, research and experimentation on the public communication of science and scientific dissemination activities.

Most of the IREA's research activities share the exploitation of electromagnetic fields to develop and implement services and products for the benefit of society. In particular, IREA's research activities have significant impact in several important applicative fields, such as environmental monitoring, the assessment of natural and anthropic risks, the protection of public health from risk of exposure to electromagnetic fields and the use of electromagnetic fields in medicine diagnostics and therapy.

Regarding the environmental monitoring, the Institute's consolidated skills in the fields of Earth Observation technologies, also integrated with airborne and ground-based sensing, have allowed the development of innovative methodologies and technologies for detecting and characterizing environmental parameters such as the health status of aquatic ecosystems and coastal areas, the distribution of irrigated areas, the soil tillage practices, the extent of wildfires, the nutritional status of crops, and plant diseases.

Furthermore, thanks to its expertise in computer science for the management and treatment of geospatial data, IREA has developed infrastructures for data management with a specific interest in environmental protection.

The topic of safety of the natural and built environment is also central to the Institute's research activities. IREA is involved in numerous research projects ranging from monitoring the territory for the identification and evaluation of risk factors to the surveillance of infrastructures and the built environment, to the protection of cultural heritage, to safety at sea.

IREA researchers have successfully implemented and provided services and tools for monitoring different types of risks, such as seismic, volcanic, hydrogeological, and flooding hazards.

For the above-mentioned needs IREA researchers have achieved scientific advancements not only for single observation techniques but they have also exploited the integration between satellite observations and airborne and ground-based ones. In this way, it was possible to build integrated approaches able to make a multi-scale, multi-resolution, multi-depth monitoring of the environment, buildings and infrastructures.

In particular, IREA is the Competence Centre for the Italian Civil Protection Department for ground deformation monitoring detected by applying satellite interferometric radar techniques. In this context, IREA generates displacement maps induced by the principal national and international seismic events and monitors the ground deformations of the main active Italian volcanoes.

Furthermore, advanced modelling is performed for the sources (mainly in terms of location and extent) responsible for the ground deformations observed and detected by remote sensing radar technology.

Regarding the research activities concerning health, they are devoted to studying the interactions between non-ionizing electromagnetic fields and biological systems to assess health risks and contribute to the development of evidence-based guidelines and regulatory frameworks to minimize potential risks and promote public safety.

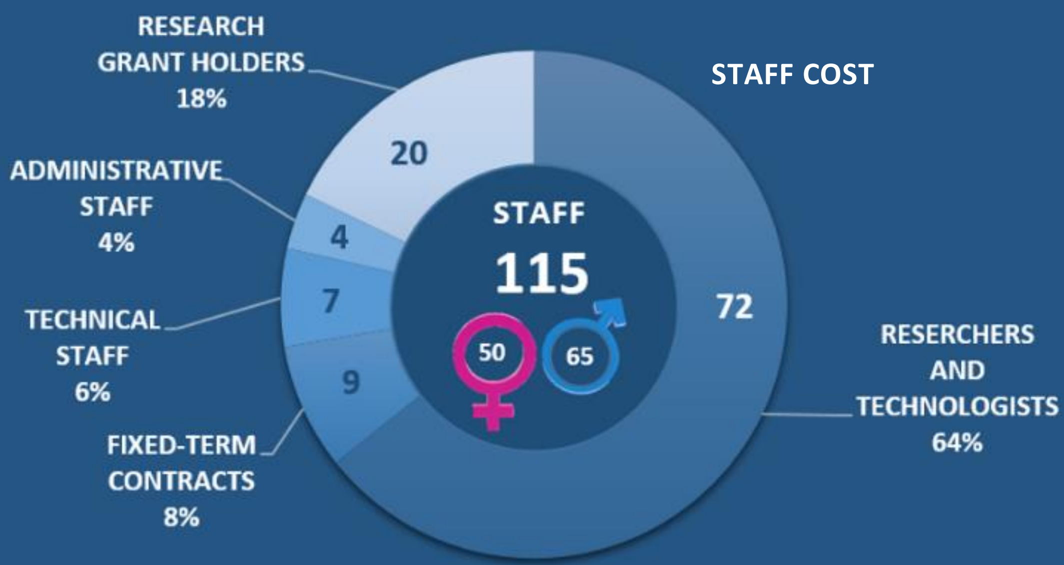
Besides, IREA research activities aim at the design, development, and validation of new diagnostic technologies exploiting the interaction between electromagnetic fields and the human body for the early and non-invasive diagnosis of some pathologies of high social relevance, such as breast cancer or stroke, through the use of non-ionizing (microwave) radiations, therefore safe for patients. Moreover, radar systems for remote characterization of vital signs (respiration and heartbeat frequency rates) and optical sensors for point-of-care analysis are developed.

Research activities are also ongoing for the development of a technology exploiting high-voltage electrical pulses to enable the electroporation phenomenon of interest for cancer treatment.

Finally, IREA dedicates some of its activities to the public communication of science, considered both as a means of valorizing research activities and disseminating knowledge and as a research area. In the first case, communication is performed through the institutional website and social channels, informative articles, videos, participation in events for the dissemination of science, popular exhibitions and activities for schools, as well as within research projects. In the second case, public communication is research itself, with the aim of investigating the role of the scientific community in the interaction between knowledge and society.

OVERVIEW

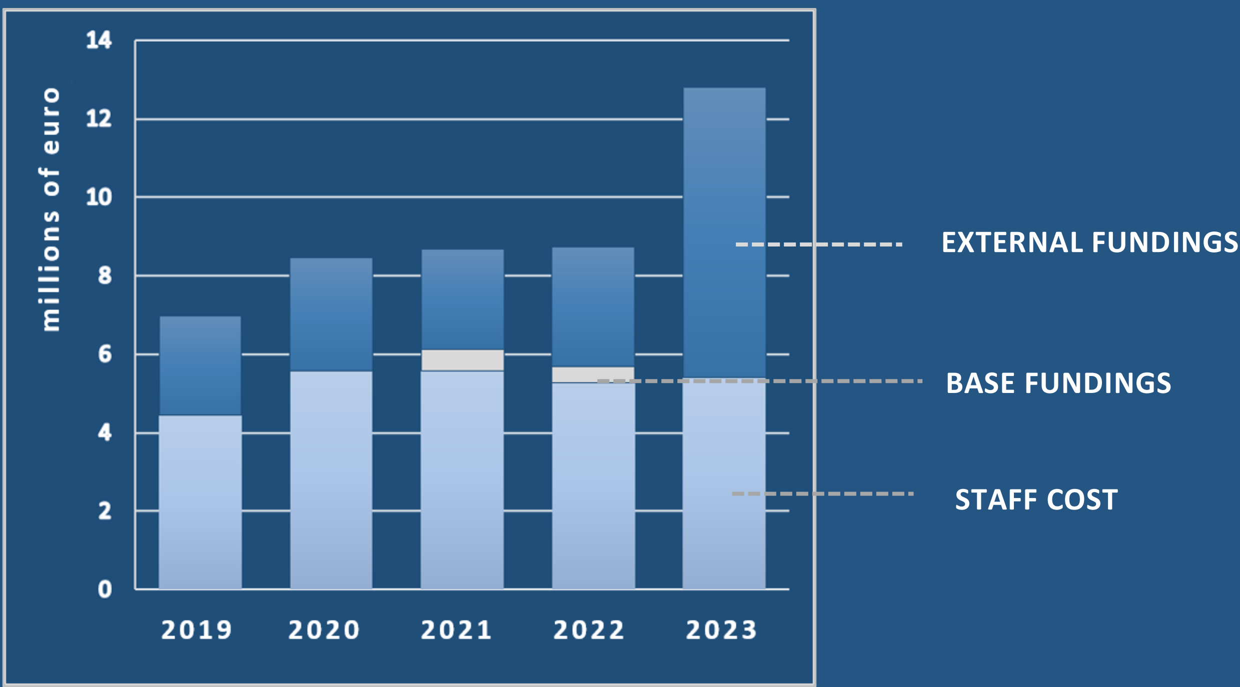
IREA IN NUMBERS



PHD STUDENTS 6

SCHOLARSHIP HOLDERS 1

BUDGET DEVELOPMENT



OVERVIEW

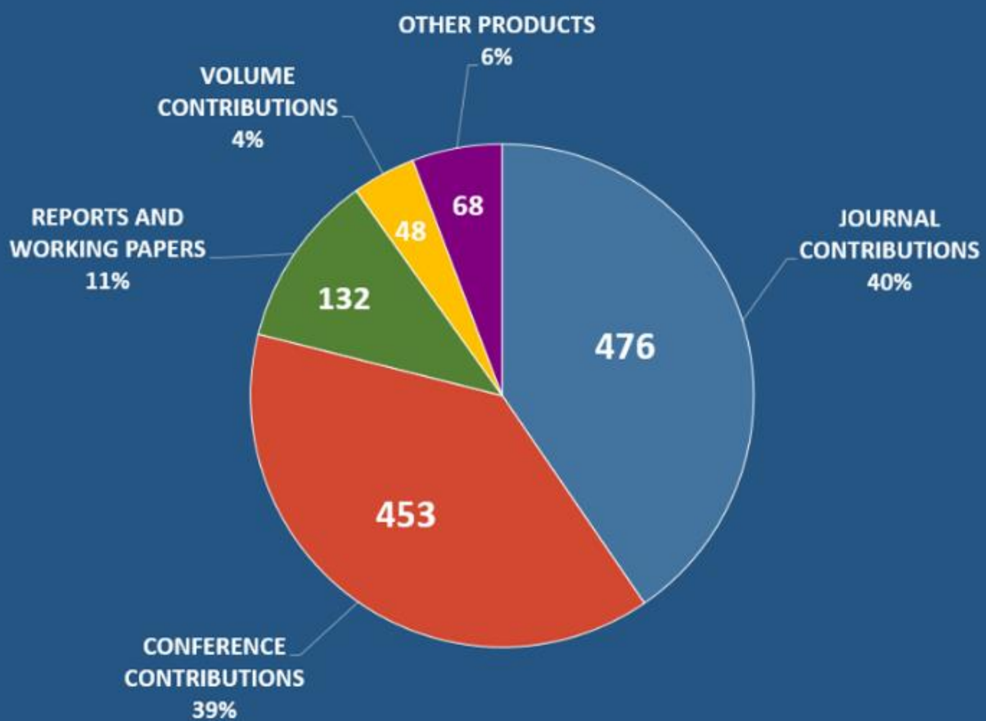
IREA IN NUMBERS

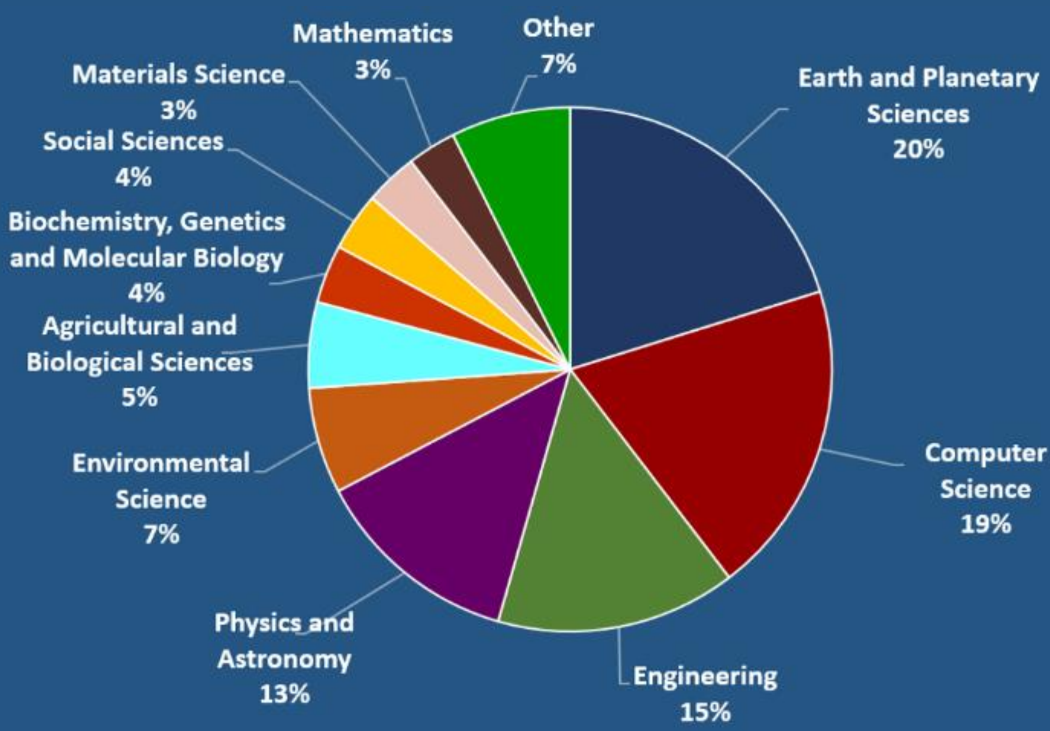
LAST FIVE-YEAR SCIENTIFIC PRODUCTION

2019-2023

1177 products selected from CNR IRIS

ordered by type





721 products selected from Scopus

ordered by subject area

ENVIRONMENT

Environmental monitoring activities play a vital role in our understanding of the Earth's ecosystems and the impact of human activities on the environment. By monitoring the environment, scientists and policymakers can make informed decisions to protect and conserve natural resources, mitigate pollution, and promote sustainable development.

These activities involve the systematic collection, processing, analysis, and interpretation of data to assess the health and quality of various environmental components, including air, water, soil, vegetation and biodiversity, identify emerging threats, and implement effective strategies for environmental protection and sustainable development.

Earth Observation (EO) technologies play a crucial role in environmental monitoring. Indeed, satellite imagery provides a broader perspective, allowing for continuous and synoptic monitoring of large-scale changes in the surface and subsoil. Remote sensing data, combined with measurements by other observational platforms (airborne, drones, ground-based) enhance our understanding of environmental processes, support early warning systems, and facilitate effective and reliable decision-making in environmental management.

These technologies, and the related methodologies, are crucial for a wide range of applications.

They are commonly used for vegetation monitoring, providing data on their cover, water content, and health at regional to global scales.

In agriculture, EO technologies help farmers optimize crop management by assessing plant health, detecting diseases or pests, monitoring crop growth stages, and determining irrigation or fertilizer requirements.

EO technologies have proved crucial for monitoring forests and wildfires, aquatic ecosystems, water management, soil use, and marine pollution.

IREA has considerable expertise in using Earth Observation technologies for environmental monitoring with frequent and continuous observations over time. The Institute's involvement in various national and international projects has enabled the consolidation of its image/data processing and analysis capabilities and the set-up of approaches for the provision of different types of services and products.

We have to stress the significance of in situ data acquisition for the calibration and validation of algorithms as well as the development of in-situ observation technologies as the other key element in environmental monitoring. In this field, IREA researchers have been active for many years.

An important example is provided by the research activities in the area of sensors for water analysis. Parameters like chemicals, pollutants and organic contaminants are measured by sensors developed by IREA researchers to determine the quality of freshwaters and marine-costal waters. The collected data are crucial for managing water resources sustainably, protecting aquatic habitats, and ensuring safe drinking water supplies.

Furthermore, IREA researchers have contributed to the development and implementation of the National Fisheries Data Portal which has the aim of providing the public with information on the status of resources and performance of fishery in EU sea basins. In the same general framework, IREA researchers are also working on the development of semantic research infrastructures for environmental data management aimed at a more thorough understanding and efficient mitigation management of environmental impacts on the Earth system.

SOIL USE

Monitoring Tillage change using Sentinel-1 and Sentinel-2 data

Giuseppe Satalino, Davide Palmisano, Anna Balenzano, Francesco Lovergine, Francesco Mattia

Soil health and sustainable soil use are of vital importance in climate change control. An important element of the strategy to protect and restore soils, which is the goal of the EU Soil Strategy for 2030, is to achieve a change in conventional soil management practices.

Conventional tillage practices, which consist of turning over the soil by mechanical movement, involve approximately 66% of the arable land in Europe. However, it has been demonstrated that excessive, long-term use of this practice has an increasingly negative impact on soil quality. There is an urgent need to reduce water and biodiversity loss, soil erosion and carbon dioxide release. For these reasons, minimal soil disturbance (i.e. Conservation or Zero tillage practices) has been widely promoted by, e.g., FAO and the new EU CAP 2023-27.

To evaluate the effective use of minimum tillage practises, it is important to set up appropriate procedures to assess their level of adoption at a European scale. Such a task is very difficult to be addressed by in situ observations, which would be extremely expensive and would likely not be able to collect the large amount of data needed in a timely manner. Earth Observation (EO), conversely, can effectively support the large-scale detection of tillage practices.

The features associated with tillage and detectable by EO systems are the changes in residue cover and surface roughness. The former can be identified by using passive multispectral systems, while the latter plays an important role in the radar response of agricultural soils.

IREA has developed a methodology to map tillage practises at high resolution (e.g. ~100m) by using Copernicus Sentinel-1 (S-1) & Sentinel-2 (S-2) data. The methodology exploits change-detection strategies, which are applied to bare or scarcely vegetated fields. The product is a proof-of-concept service derived from agricultural areas and consists of binary maps of surface roughness changes related to tillage practices.

The adopted methodology consists of two main steps. First, S2 or S1 data in case of cloud cover is exploited to identify bare or sparsely vegetated areas where tillage practices are usually carried out. At the second step, S-1 radar data are processed to discriminate soil changes due to surface roughness from those due to soil moisture. The rationale used to discriminate these two types of soil changes is that surface roughness due to tillage practices varies at the "field" scale and unevenly in space, while soil moisture is rather uniform at a larger scale due to rainfall events.

Therefore, the S-1 changes observed only at the "local" scale (0,1 km) are classified as due to

Tillage change map over Apulian Tavoliere (Italy) with the events identified between 5 - 11 May, 2021. Fields are outlined in black by parcel borders. Rolled fields are in yellow, ploughed fields are in red, whereas bare and vegetated fields are in grey and green, respectively.

Tillage change map over Castilla y León (Spain) with the events identified between 11 - 17 July, 2021. Fields are outlined in black by parcel borders. Rolled fields are in yellow, ploughed fields are in red, whereas bare and vegetated fields are in grey and green, respectively.

roughness changes, while those occurring both at the "local" and "intermediate" scale (5 km) are attributed to precipitations.

Figures show the effectiveness of the proposed strategy in generating tillage change maps over two agricultural areas, respectively in the Apulian Tavoliere (Italy) and Castilla y León (Spain). The yellow and red polygons in the maps are the rolled and ploughed fields identified by the methodology between two S-1 consecutive acquisition dates. Future work will be devoted to assessing the method at the regional/national scale.

CONTACT

Giuseppe Satalino

Phone +39 080-5929435

satalino.g@irea.cnr.it

WATER RESOURCE

High resolution Surface Soil Moisture for irrigation monitoring

Anna Balenzano, Davide Palmisano, Giuseppe Satalino, Francesco Lovergine, Francesco Mattia

Improving irrigation management can contribute to meeting the sustainable development challenge for food and water security. For instance, over the Mediterranean basin, irrigated agriculture represents 65% of total water consumption and a further increase is expected due to the effects of climate change in the near future.

Such a scenario may not be sustainable and threatens to undermine the social and economic development of the Mediterranean "fragile" area. Specific responses to mitigate, adapt and cope with the effects of accelerating water scarcity involve the necessity of integrated water resources management and monitoring.

Earth Observation (EO) based geo-information can largely contribute to more informed management of water resources. For instance, the space and time distribution of irrigated areas is a necessary input to simulate the water withdrawal, which is vital information for effective water management. In particular, the early detection of irrigated extent can be valuable to plan and optimize the delivery of water resources, on a basin scale, from centres of irrigation management or reclamation consortia.

IREA is engaged in developing EO algorithms to retrieve Surface Soil Moisture (SSM) at a very high resolution (~100m) and large scale and in demonstrating SSM value for the timely identification of irrigated fields.

While vegetation indexes – derived from passive multispectral satellite imagery - are sensitive to the greenness of the canopy, hence, showing an indirect dependence on the water supply, SSM at high resolution – derived from Synthetic Aperture Radar (SAR) active microwave satellite systems – identifies the high level of soil wetness due to the irrigation events. Therefore, SSM can detect irrigation well before crop emergence. Furthermore, SSM can resolve the irrigation event in time, which remains unfeasible for vegetation indexes.

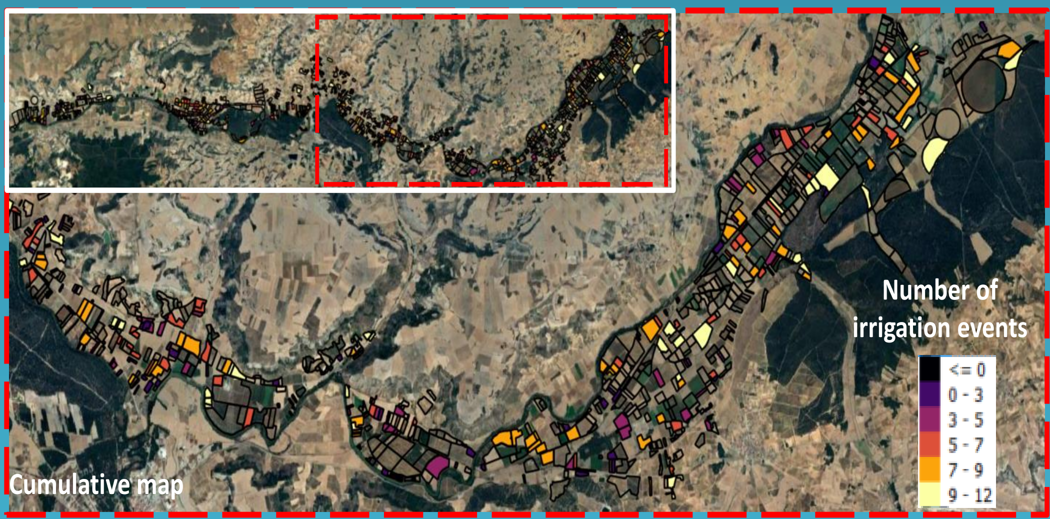
However, the SSM contrast between irrigated and non-irrigated fields tends to dissolve within a few days due to evaporation and percolation. Therefore, a crucial factor affecting SSM irrigation detection is the temporal resolution (time revisit) of SAR satellite observations.

IREA research activities have allowed us to verify that a maximum revisit of three days is necessary to capture approximately 75% of irrigated fields and a one-day revisit would significantly improve the performance. Moreover, SSM is highly valuable for the early detection of irrigation events, while vegetation indexes are more reliable at the late stages of the growing season.

Figure 1 provides an example of mapping irrigated wheat fields based on EO SSM data acquired on

Example of irrigated/non-irrigated map, derived from EO SSM data over the Riaza irrigation district in Castilla y León region (Spain) on April 22, 2017. A zoomed-in view of the inset (red dashed rectangle) is shown

Cumulative map of the irrigated areas from April to June 2017 at the Riaza irrigation district



April 22, 2017. The area is the Riaza irrigation district in the Castilla y León region (Spain). Figure 2 shows the cumulative map, from April to June, of irrigated/non-irrigated fields. The colours code the number of irrigation events per field.

Future work will be dedicated to assessing the use of SSM to detect and classify irrigated fields in the area of the Mediterranean basin. In particular, the impact of drip irrigation versus sprinkler or mobile booms will be investigated on the capabilities of EO in detecting irrigated fields.

CONTACT

Anna Balenzano

Phone +39 080-5929444

balenzano.a@irea.cnr.it

AGRICULTURE

Sustainable agriculture: the role of remote sensing

Gabriele Candiani, Monica Pepe, Francesco Nutini, Alberto Crema, Marina Ranghetti, Lorenzo Parigi, Katayoun Fakherifard, Giulio Tellina, Mirco Boschetti

Sustainable agriculture (SA) is at the heart of the 2030 United Nations Agenda as a fundamental step to securing zero hunger and protecting the environment. SA has the goal to ensure today society's food and material needs without compromising natural resources and the environment for future generations.

Meeting global food security needs remains a challenge, as food and protein demand increases at a rate even faster than population growth with a potentially dramatic consequence for environmental and humanitarian aspects. SA goal must be achieved by producing more (food and material production) with less (land exploitation and natural resources consumption) to maintain a balance between food demand and production capacity of agricultural systems from a long-term perspective and taking into account the impact of climate change.

Considering this scenario, farmers are forced to increase yields while protecting their most important production factors: soil from degradation, water and air from pollution and atmosphere from emissions of greenhouse gases.

To achieve this goal, agricultural monitoring is a fundamental step to provide reliable and timely crop status information as well as an essential prerequisite for several activities that aim at quantifying crop performance in time and space, detecting plant damages, and monitoring dynamic crop growth. Such a geo-spatial information is fundamental to support sustainable agro-practices during the season, to provide indicators for crop production forecast and to highlight potential critical conditions.

In this context, remote sensing is recognised as an essential source of data, which can contribute to improve agricultural activities and farm management besides supporting control and implementation of policies.

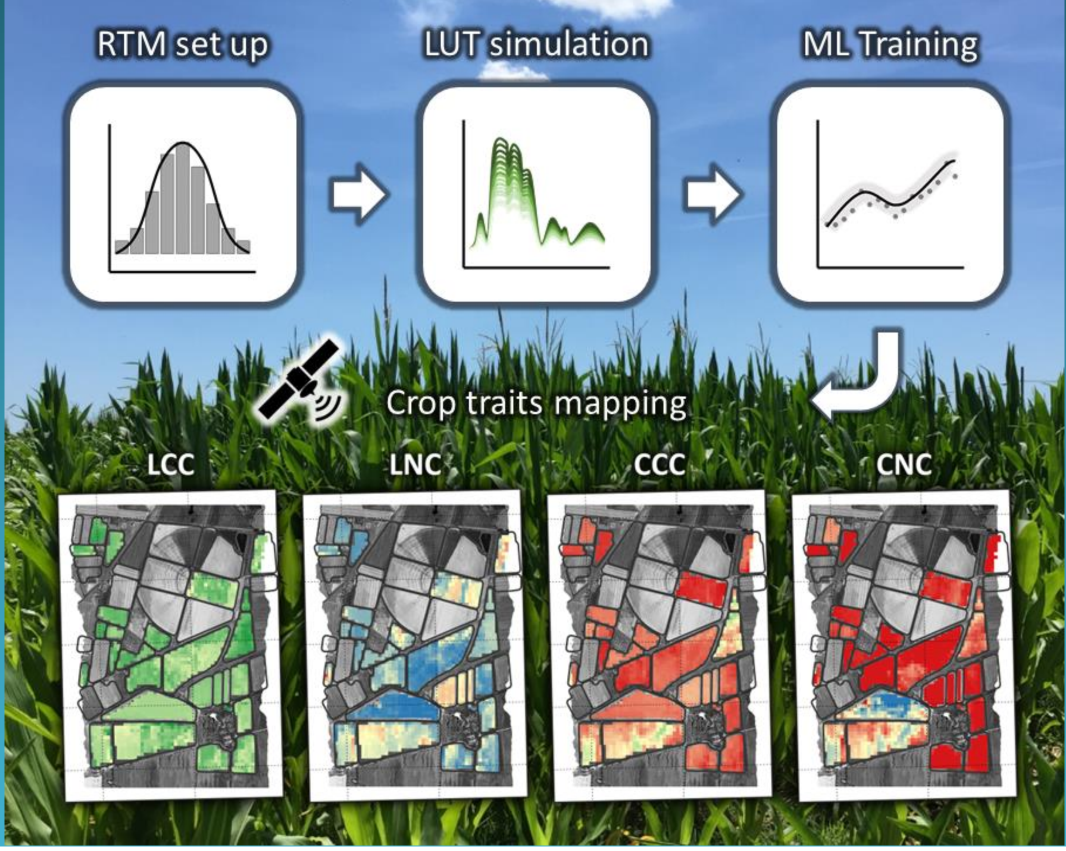
IREA carries out research and development activities exploiting remote sensing to produce added value information as a contribution to crop monitoring at local and regional scales, generating knowledge on crop status, investigating temporal dynamics of crop growth as well as detecting adoption of sustainable agro-practices.

In developed and industrialised countries, geo-information products can be used to provide farmers with decision-supporting spatial information (crop traits maps), able to highlight within-field crop variability, which is a fundamental tool to adopt site-specific management. Remote sensing data are recognised as one major source of data to generate the requested bio-geophysical information.

The availability of operational multispectral sensors (e.g., ESA's Sentinel 2) and the continuous development of hyperspectral sensors (e.g., ASI's PRISMA) offer new possibilities for the development of investigation tools in agriculture.

In the last few years, IREA has used state-of-the-art

The data processing workflow for estimating Leaf Chlorophyll Content (LCC), Leaf Nitrogen Content (LNC), Leaf Water Content (LWC), Canopy Nitrogen Content spatial maps as indicators of crop traits



estimation methods to generate knowledge from data, based on advanced statistical and physically-based approaches. Recently, IREA investigated the hybrid approach, an innovative methodology, which combines the Radiative Transfer Modelling capability to simulate a wide range of crop conditions with the Machine Learning Regression Algorithms flexibility and computationally efficient capability to solve non-linear complex problems. Generated maps represent the expected geo-spatial information to implement digital agriculture solutions, within the precision farming paradigm.

To set up such a methodological solution, a significant part of the work has been also devoted to fieldwork activities to acquire dataset for the calibration/ validation of Earth Observation data and related products. Furthermore, the operational production and analysis of continuously generated information are fundamental to perform time series analysis within a season and along seasons, with the aim of identifying the occurrence of crop phenological stages and analysing their relation with agro-practices, technological innovation and climate change trends.

Finally, the analysis of field conditions after harvesting (post season), by mapping the presence and abundance of crop residues, is an expected contribution of EO applications to monitor/control the implementation and rate of conservation practices in agriculture (European Commission, 2018). It also provides methods for eco-system services applications in other domains, in a way that this has become a key variable in the design of new satellite missions.

Thanks to spectroscopic approaches, it is possible to assess the relative abundance of crop residues as an indicator of crop tracking and management as it is connected to tillage, crop rotations, and harvesting practices.

CONTACT

Mirco Boschetti

Phone +39 02-23699297

boschetti.m@irea.cnr.it

VEGETATION WATER CONTENT

Satellite observations for Vegetation Water Content retrieval

Davide Palmisano, Anna Balenzano, Giuseppe Satalino, Francesco Lovergine, Antonella Belmonte, Francesco Mattia

Vegetation water content (VWC) refers to the weight of water present in the epigeal part of the plant per unit area and is measured in kg/m2. In agriculture, VWC is an important parameter indicating plant health.

Indeed, plant water stress is a limiting factor in agricultural productivity. It occurs when reduced water supply from the soil leads to morphological, physiological and biochemical alterations in the plant. Therefore, VWC estimates can be used, for example, to support decision-making during irrigation practices, drought monitoring, and as an indicator of plant maturity status, in terms of the optimal amount of residual water for harvesting.

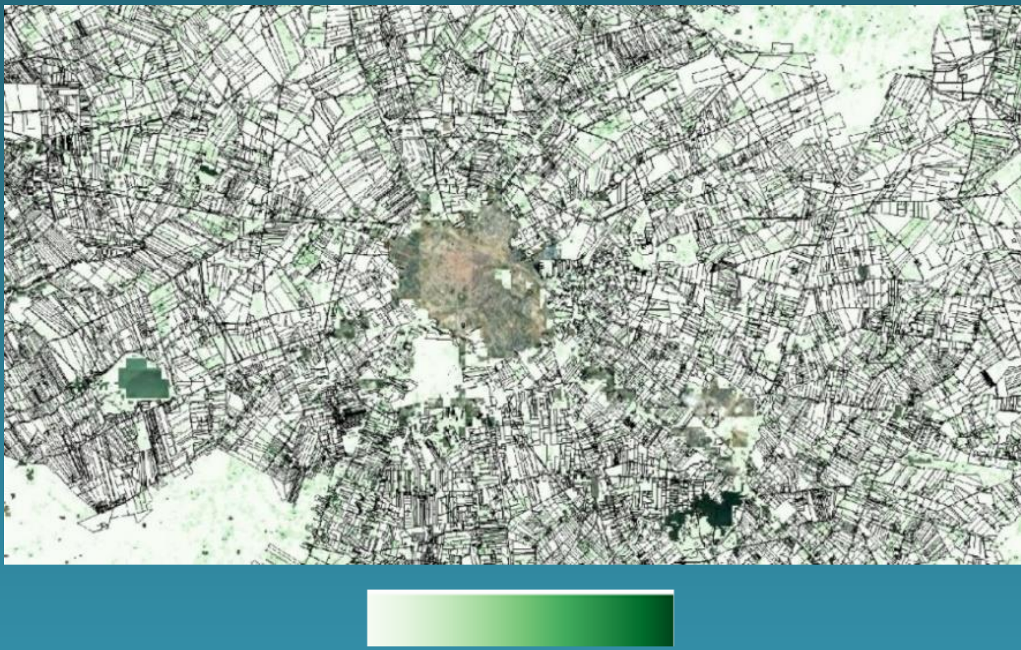
Some plant indices, derived from optical multispectral data, have been proposed as proxies for the VWC, see for example Normalized Difference Vegetation Index or the Normalized Difference Water Index. These indices are mostly sensitive to 'greenness' conditions, which in some cases can correlate well with VWC. However, the availability of optical data is affected by lighting and meteorological conditions.

Conversely, radar data show a direct sensitivity to the dielectric properties of the vegetation, which are related to VWC. Various methods based on radar data have been proposed, such as the one based on measurements of SAR backscattering in C- and L-band, and for different polarisations.

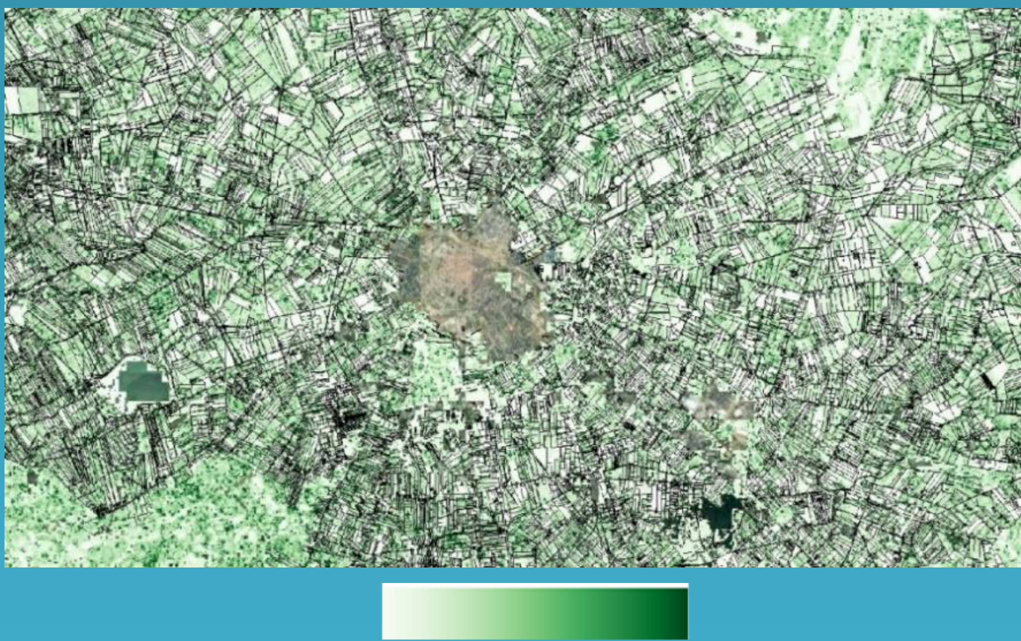
IREA has developed and assessed a method transforming the time series of Sentinel-1 SAR data into corresponding smoothed time series of VWC, which are effective to follow the temporal behaviour expected in crop growth models.

The approach has been tested against in situ observations with good results. Figures show an example of two VWC maps retrieved from S-1 data over Apulian Tavoliere at the beginning (around mid-February) and at the season peak (around the end of April). Parcel boundary information has been overlaid on the maps.

An extensive validation of the approach is now in progress, including a cross-comparison between the developed approach and other optical multi-spectral and hyperspectral and radar indexes.



Retrieved VWC on February 16, 2021 over Apulian Tavoliere



Retrieved VWC on April 29, 2021 over Apulian Tavoliere

CONTACT

Davide Palmisano

Phone +39 080- 5929456

palmisano.d@irea.cnr.it

FOOD

PRODUCT

QUALITY

A web services infrastructure for the traceability and promotion of the quality of food products

Gloria Bordogna, Paola Carrara, Simone Lella, Anna Rampini, Paolo Tagliolato

The agri-food sector needs to meet consumer expectations regarding the quality, safety and sustainability of agri-food products, given the fundamental role of food for both the well-being and health of citizens and for preventing specific pathologies related to dietary imbalances.

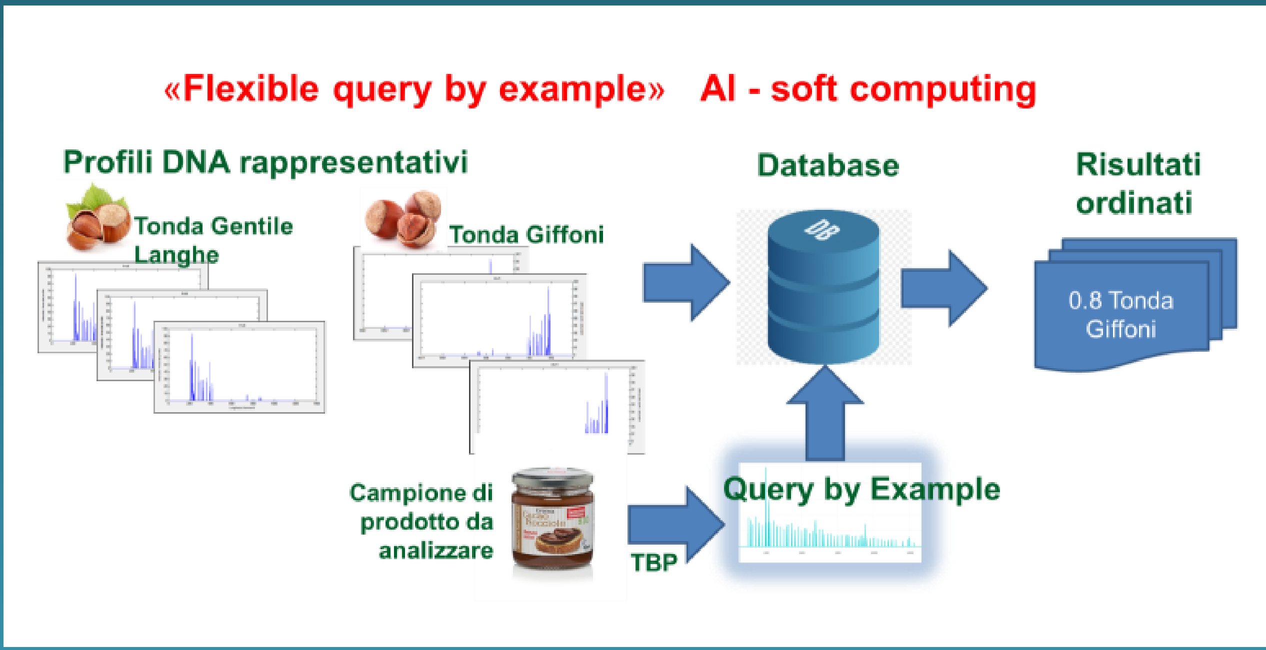
In this context, IREA has designed and implemented a web services infrastructure for the traceability and promotion of the quality of food products by facilitating communication between consumers and agri-food companies and collaboration between companies and research institutes carrying out product quality analyses.

The infrastructure architecture has been designed basing on the microservices paradigm and using open-source libraries. User access to the services and the authenticity of the stored information are managed securely, guaranteeing the inalterability of the contents. The database is implemented through a document base (MongoDB) with the main aim of integrating heterogeneous information. Finally, the algorithms for decision support in recognising raw materials in food products are based on soft computing methods.

Besides the label consultation service, accessible to consumers by scanning the QRcode label printed on the food product package, the infrastructure includes three web services dedicated to the analysis laboratories, the manufacturing companies, and the manager of the authentication process. In this way, the entire production process (traceability) of food, the packaging adopted, as well as its preservation and storability over time, is documented and reported in a dynamic, interactive and multimodal label. The content is updated in proximity to the expiration date and, if new analyses are carried out, the corresponding results are added to the content already present, enabling continuous monitoring of the product quality and perishability, already on the distributors' shelves, and the communication of the results to consumers. The label can be "listened to", and the consumer can provide his or her rating for the product and know the average rating expressed by other buyers.

Finally, the service available at the laboratories that carry out the genetic certification of the products is a decision support system (DSS). DSS helps biologists recognize raw materials by comparing DNA barcode diagrams that characterize products thanks to soft computing methods.

Compared to the manual recognition performed by a biologist through visual inspections of the DNA bar code diagrams, the automatic process guaranties replicability of the results, uniformity of the criteria applied to different samples, sensitivity analysis of the results by varying the parameters that regulate



Web service to support the recognition of raw materials present in food products by comparing DNA barcode diagrams

Smart labels (interactive, dynamic and multimodal) with updated information on the traceability of quality analyses of agri-food products

the similarity match, and scalability when the number of the raw materials in the database increases.

CONTACT

Paola Carrara

Phone +39 02-23699295

carrara.p@irea.cnr.it

FOOD PRODUCT QUALITY

Electromagnetic technologies for food quality inspection

Ilaria Catapano, Lorenzo Crocco, Roberta Palmeri, Gianluca Persichetti, Rosa Scapaticci, Sonia Zappia

Food is one of the main and worldwide-recognized assets of “made in Italy”. The overall economic impact of the food industry in Italy in 2017 was almost 35 Billion €, and such a figure is expected to further increase in the future. In the food industry, foreign body contamination, packaging failures, or items with poor characteristics (texture, appearance) are among the main sources of customers’ complaints against manufacturers, resulting in loss of brand loyalty and large recall expenses. The food industry, and not only at a national level, is particularly exposed to this type of problem, especially today when conscious consumers pay much more attention to the quality and integrity of the food purchased.

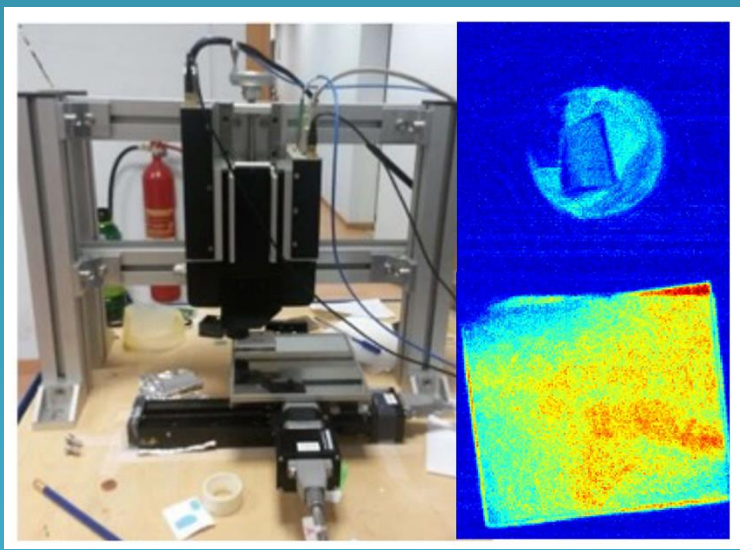
To cope with these issues, technologies such as metal detectors (MD), X-ray (XRI) and near-infrared (NIR) imaging are currently adopted in the food industry to monitor food quality and safety. However, the occurrence of incidents remains significant.

The technologies based on electromagnetic waves developed by IREA researchers can provide a cost-effective answer to these needs.

As far as the inspection of food products along the production line, the IREA know-how in non-invasive diagnostics techniques at microwave (MW) and terahertz (THz) frequencies is exploited to take advantage of the different capabilities of these portions of the EM spectrum. In particular, the synergic use of MW and THz techniques allows us to simultaneously address the need to have high-resolution images to detect tiny defects in packaging and alterations on the product’s surface (underneath the package), and the need to penetrate the food product to detect the presence of foreign bodies in-depth, as well as assessing its overall properties. In fact, THz radiation can gather information on the surface of the scanned object and its most superficial portion, revealing defects and/or package failures. Conversely, MW radiation can propagate in depth within the item under test, revealing its internal structure. Moreover, since both MWs and THz interact with the EM properties of the target, and because these properties are directly related to the water content of the material, the gathered information can be also used to inspect food quality.

The assessed expertise of IREA researchers in the design of spectroscopic sensors for the monitoring of liquid substances lays the ground for designing sensors tailored to the specific needs arising in the monitoring of liquid foods (e.g., wines, oils, honey, sweet drinks) both for the control of production processes and to determine adulterations. In particular, the activity of IREA is aimed at developing sensors based on Raman spectroscopy. This technique, due to its ability to identify the molecular

The MW imaging device developed by IREA researchers in collaboration with researchers from Politecnico di Torino in the framework of the BEST-FOOD project



The THz imaging device available at IREA laboratories, exploited in the BEST-FOOD project to reveal the presence of contaminants in food products underneath the packaging

composition in multicomponent samples, has demonstrated good potential for the rapid and non-destructive evaluation of foods.

IREA often, but not exclusively, uses this technique by combining it with the jet waveguide approach, a sort of liquid optical fiber, which allows a large capacity for collecting light useful for detection and is particularly suitable in the case of liquid samples.

CONTACT

Lorenzo Crocco

Phone +39 081-7620645

crocco.l@irea.cnr.it

Plant disease monitoring from remote sensed data by using machine learning techniques

Annarita D'Addabbo, Antonella Belmonte, Fabio Bovenga, Francesco Lovergine, Alberto Refice

The problem of plant diseases is a worldwide issue, which has critical effects on the quality and quantity of agricultural products, changing or interrupting crop vital functions such as photosynthesis and transpiration. Accurate recognition of crop diseases is very important, especially at an early stage, i.e. before the symptoms appear visually. This is particularly important when no remedies are available, so that the only way to stop the spread of a pathogen is the eradication of infected plants. Nowadays, diagnostic checks are often made by visual inspection or by sophisticated biological tests, such as the quantitative real time-Polymerase-Chain-Reaction (qPCR), performed on sampled leaves or twigs. These procedures are complex, time-consuming and expensive. Moreover, they are often ineffective because early detection ought to be made on short temporal and large spatial scales in order to reduce the infection risk for the surrounding plants, which is currently hardly feasible through ground campaigns.

For these reasons, the use of multi/hyperspectral and thermal data, remotely acquired by sensors mounted on different platforms, is being assessed. Remotely sensed data have been demonstrated to be an effective tool for the detection of several plant diseases. Statistically well-founded methodologies are required to extract useful information from such data, in order to automatically and accurately classify healthy and infected trees. Machine learning or deep learning approaches have been proposed in the literature, showing promising experimental results.

IREA is now involved in the challenging task of early detection of Xylella fastidiosa (Xf) from hyperspectral and thermal data acquired by sensors on airplanes and Unmanned Aerial Vehicles (UAVs). Xf is a plant pathogen affecting 679 plant species worldwide. In the last years, it has been identified as the bacterium causing a devastating disease on olive trees in the Apulia Region (Italy), with a great impact on the landscape and the agricultural yields, thus causing significant economic losses.

Three data acquisition campaigns were performed in 2021 and 2022 in different zones of the Apulia Region, according to indications from Phytosanitary Authorities, in the so-called "containment area", the last northwards 20-km strip of the infected zone, and in the "buffer zone" (10 km width) immediately north of it, both of which cross the Region in the east-west direction, from the Adriatic to the Ionian coast.

Other campaigns were conducted in 2023. A wealth of data, with different spectral and spatial resolutions, has been collected enabling us to follow the Xf evolution in time.

The state of the art to analyze hyperspectral and thermal remotely sensed data is represented by the Support Vector Machine (SVM) algorithm. However,

A RGB composition of 3 bands of hyperspectral image acquired in the agricultural area of Gorgognolo (BR) with the label associated to some trees (Infected/Healthy)

at the present stage, the spread of Xf is fortunately slowing down, with many areas where the rate of infected trees is very low. For this reason, IREA researchers have considered other classification algorithms, such as RUSBoost, which stands for Random Under Sampling (RUS) boosting, a technique developed for automatic learning from skewed training data.

In addition, IREA researchers are working on a detailed analysis aimed at identifying spectral features (vegetation indices, biological parameters obtained through the inversion of opportune radiative transfer models) better correlated with the pathology at hand. The objective of this study is manifold: reducing the amount of data to be handled, capturing some insight on the pathology and its spreading, and paving the way to the realization of customized sensors.

CONTACT

Annarita D'Addabbo

Phone +39 080-5929421

daddabbo.a@irea.cnr.it

FIRES

Forest ecosystems and fire disturbance

Daniela Stroppiana, Mirco Boschetti, Pietro Alessandro Brivio, Antonio Pepe

Fires have numerous and complex effects on geological, hydrological, ecological, and economic systems. “Fire disturbance” is one of the Essential Climate Variables addressed by the ESA Climate Change Initiative. IREA research activities have the main scope to provide long-term burned area information for global vegetation and atmospheric modellers.

In many areas of the world, the frequency and intensity of wildfires have increased in recent years and are expected to worsen with ongoing climatic and land use changes.

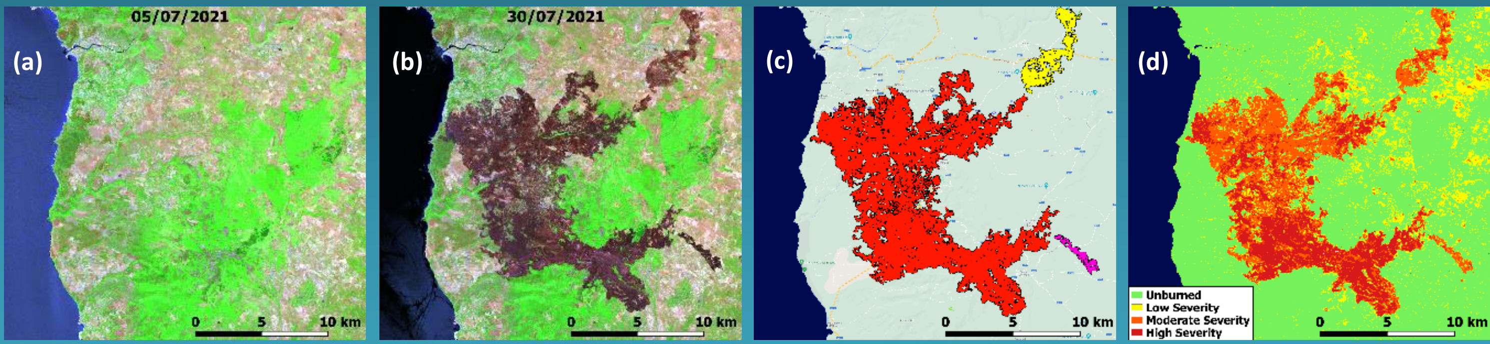
In recent years, extreme fire events have been an emerging and major threat in many areas of the world, and, in particular, in Mediterranean countries and Italy. Worldwide, severe fires occurred in South America (Chile, February 2023), Australia (Black Summer, 2019-2020), and California (every summer). In Southern Europe, several extreme events were concentrated in the last five years: Spain (2022), Turkey and Italy in the summer of 2021 (Sardinia, Calabria and Sicily), Greece (2021, 2022), Portugal (Pedrógão Gramde, 2017), and many others. This trend is expected to be exacerbated by climate and land use changes, and the Mediterranean is considered a hot spot for these events as it is experiencing stronger heat waves and longer periods of drought conditions due to global warming.

Remote Sensing technology has proved to bring key source data for monitoring wildfires by exploiting both optical/multi-spectral and microwave satellite sensors. Optical multispectral satellite observations have been widely used for monitoring wildfires and to support fire risk estimation (e.g. indicator of vegetation drought/stress condition), fuel availability and characteristics (e.g. vegetation compound typology and moisture content), active fire detection, burned area mapping, assessment of burn severity (e.g. damage induced by the fire on the vegetation) and monitoring vegetation recovery.

In this framework, IREA has long been working on fire monitoring, being involved in national and international projects by exploiting information from multi-spectral satellite images at regional and global scales.

The major activity has been the extraction of fire perimeters (i.e. burned area mapping) from data acquired by Earth Observation missions such as NOAA-AVHRR, SPOT-VEGETATION, NASA-MODIS and NASA Landsat providing coarse to medium spatial resolution data.

At present, the most relevant mission for regional applications is ESA Copernicus Sentinel-2, which provides image data with unprecedented high spatial and temporal resolutions. Moreover, the integration of Sentinel-2 with Landsat legacy data could further increase the temporal frequency of observation and provide 50-year time series of imagery for analysing historical trends of fire-affected areas. Sentinel missions offer also the unique opportunity of



Sentinel-2 image acquired before (a) after the fire (b) over the Montiferru region (Italy) (RGB SWIR-NIR-RED); the burned area derived with a supervised classification algorithm depicting the major fire events (c); burn severity classes derived from the difference between pre- and post-fire NBR vegetation index (d).

integrating multi-spectral and SAR data with the combined constellations of Sentinel-1 and Sentinel-2. Fire monitoring could benefit from the synergy between these systems and IREA has long been involved in research activities dealing with the development of multi-source approaches and algorithms for mapping burned areas and assessing severity.

From a methodological point of view, in the past IREA has exploited consolidated supervised and unsupervised classification algorithms. In recent years, new methods have been developed based on Fuzzy Set theory to address the uncertainty of the investigated phenomena as well as on Machine Learning algorithms to fully exploit powerful nonlinear solutions for change detection.

Under this general framework, IREA has developed an algorithm for mapping burned areas from temporal series of Sentinel-2 data (Fuzzy Burned Area mapping algorithm - FBAMA), which has been implemented as a Plugin in QGIS (Burned Area Detection-BAD) and made available also for non-expert users.

One case study was the Montiferru fire in Sardinia (Italy, summer 2021). Over this region, Sentinel-2 data and coherent/incoherent change detection indices based on Sentinel-1 data have been used to detect the areas affected by fire and to map burn severity. The figure shows burned areas detected from multitemporal Sentinel-2 images (before and after the fire) (panels a, b) by using a supervised Random Forest Algorithm (panel c) and the assessment of burn severity (panel d) estimated from the Sentinel-2 Normalized Burn Ratio (NBR) index.

Finally, IREA has long been active in the definition of methodologies and protocols for the validation of thematic map products and has recently been involved in international projects for validating global and regional burned area maps derived from EO data.

CONTACT

Daniela Stroppiana

Phone +39 02-23699288

stroppiana.d@irea.cnr.it

AQUATIC ECOSYSTEMS

Remote sensing for aquatic ecosystems

Mariano Bresciani, Monica Pinardi, Paolo Villa, Salvatore Mangano, Giacomo De Carolis, Marina Amadori, Alice Fabbretto, Rossana Caroni, Erika Piaser, Alessandro Scotti, Andrea Pellegrino, Nicola Ghirardi, Claudia Giardino

Aquatic systems, comprising lakes, rivers, ponds, lagoons wetlands and coastal areas, are crucial environments for biodiversity and ecosystem functioning and for providing vital resources and services, such as drinking water supply, irrigation, sanitation, industry, energy and recreation.

Many regions of the world are now facing serious challenges to their aquatic resources including reduced water quality, increasing damage to connected ecosystems and degradation of wetlands.

To understand and model these processes and possibly mitigate their effects it is essential to establish continuous and synoptic monitoring of biophysical variables, dealing with water conditions and aquatic habitats.

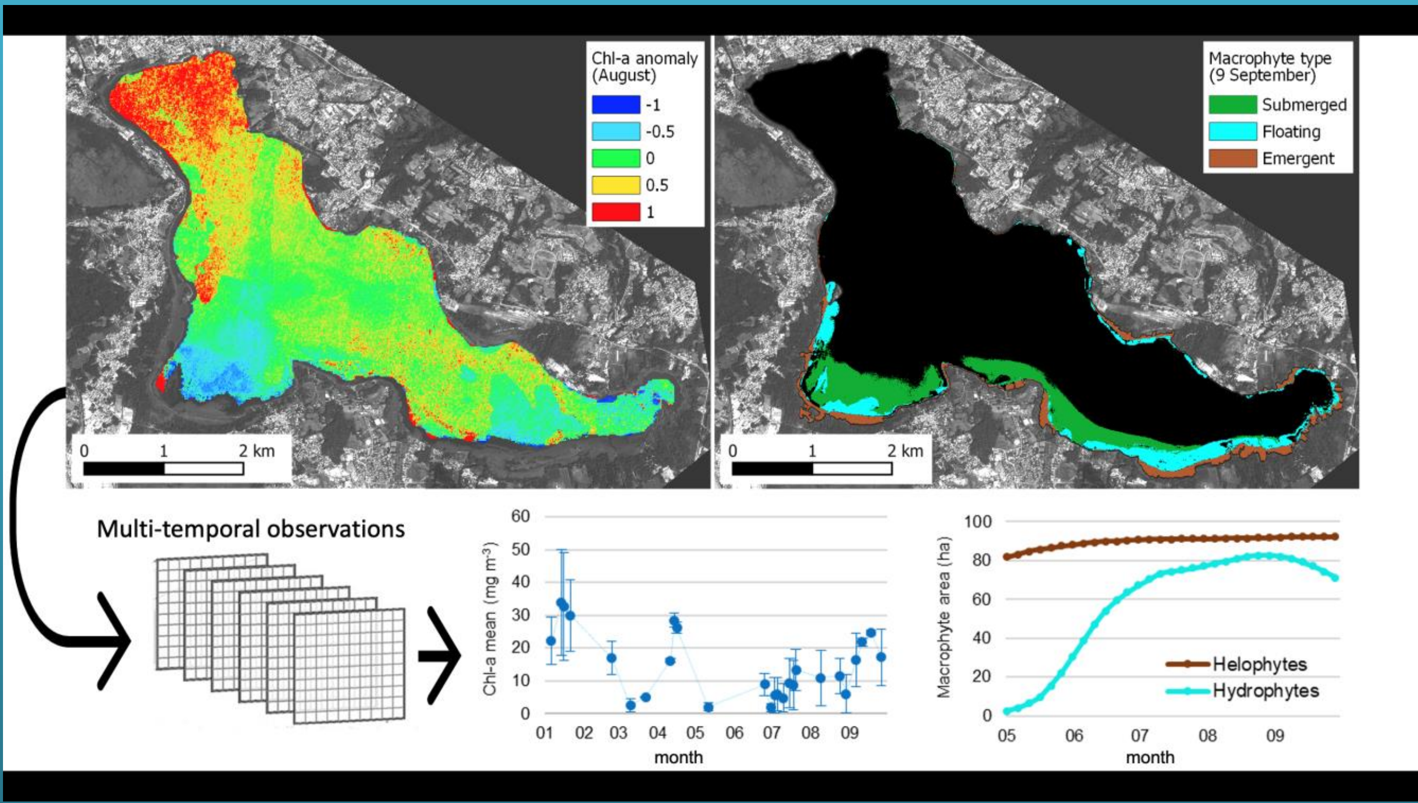
For more than three decades, remote sensing has been recognized as an essential technique for aquatic ecosystem monitoring. We have entered an unprecedented era of massive remote sensing data acquisition, including time-series records and near real-time data acquired by satellites, aircraft, drones and at-ground sensors with different spectral-spatial-temporal resolutions. Information technology solutions are enforcing the spread of remote sensing-based solutions by transforming data into knowledge, with a variety of public and private services accordingly developed for the water sector.

In such a framework, IREA is performing research and development activities on remote sensing for aquatic ecosystems from local to global scale.

We started in the Nineties, when imaging data were not easy to collect and process, and most of the challenges of inland and coastal waters remote sensing were still to be tackled. Since then, the core of activities deals with the processing and application of optical satellite data for testing and developing algorithms to estimate biophysical parameters in optically complex waters and to characterize aquatic vegetation.

Activities exploiting the advantages of imaging spectroscopy have also been established, covering spaceborne and airborne sensors, such as PRISMA and MIVIS, up to drone cameras. Within the frame of these activities, a key role is played by fieldwork, performed to support calibration and validation of remote sensing data and products, including the installation and maintenance of big infrastructures, such as fixed position autonomous radiometers and sun photometers (AERONET station).

The methods developed for processing remote sensing data allowed us to develop products and information to support effective monitoring, management, and decision-making in the water sector, as well as to study relevant processes in aquatic ecosystems, also making use of hydrodynamic modelling. This work is, for instance, delivering insights into the condition of lakes and how climate change is acting upon them.



Tracking water quality and macrophyte changes in Lake Varese from optical satellite imagery: on the left phytoplankton biomass anomaly (chlorophyll-a) from Sentinel-2, on the right aquatic vegetation coverage and type from a very high-resolution worldview

Other examples regard the support to local and regional protection agencies in monitoring aquatic vegetation and habitat conditions and water quality, in compliance with EC directives, providing alerts on water health, enabling an improved management of reservoirs used for hydropower and drinking water supply, mapping benthic habitats, submerged vegetation and coral reefs, and on detecting floating and riparian macrophytes.

CONTACT

Claudia Giardino

Phone +39 02-23699298

giardino.c@irea.cnr.it

FRESHWATERS AND MARINE-COASTAL WATER POLLUTION

Sensors for monitoring freshwaters and marine-coastal waters

Gianluca Persichetti, Genni Testa, Romeo Bernini

Knowledge of the relationships between water and the environment is of fundamental importance, especially in the present historical moment, as this precious resource is increasingly in danger due to human action. Therefore, advances in knowledge of these issues require constant monitoring of water.

IREA researchers have been active for many years in the field of in-situ water monitoring and carry out research activities in the field of sensors for water analysis.

For the development of portable sensors, IREA researchers mainly use two techniques: autofluorescence spectroscopy and Raman spectroscopy. Both approaches are particularly advantageous as these methodologies do not require any pretreatment of the sample and can, therefore, be used for online and real-time measurements. Autofluorescence spectroscopy offers a very high sensitivity compared to other techniques. Raman spectroscopy, providing a characteristic spectrum of the specific vibrations of a molecule, allows us to obtain a sort of fingerprint of the substance to be detected and is, therefore, an extremely advantageous technique due to its selectivity.

Using these spectroscopic techniques with a jet waveguide (a sort of liquid optical fiber), which can collect light in an extremely effective way, it is possible to detect many chemicals, pollutants and even microorganisms. IREA researchers were the first to use jet waveguides in portable sensors for spectroscopy.

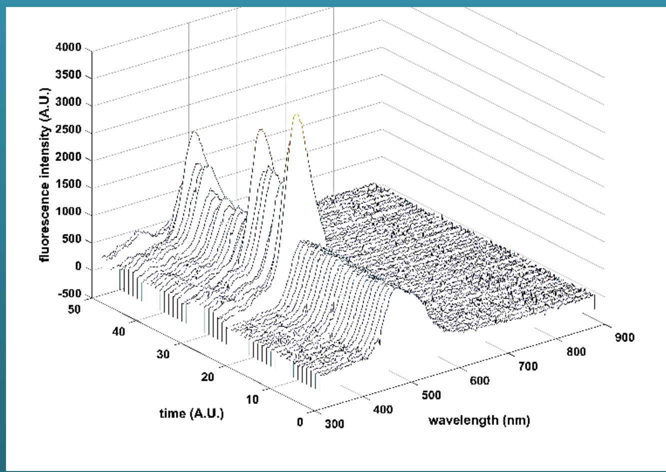
In addition to dissolved salts and gases, a small amount of organic matter is also present in fresh and marine waters. This dissolved organic matter (DOM) can have various origins: the presence of zooplankton, degradation of plants or animals and microbial or algal activity. However, it can also have an external origin, being introduced through polluted rivers or improperly purified sewers. A particularly relevant case is the one in which DOM is due to microbial activity. By consuming oxygen, this microbial community leads to elevated biochemical oxygen demand (BOD) and, thus, to subsequent collapses in oxygen levels that can be particularly devastating to aquatic ecosystems.

More generally, it can be said that DOM affects the ecological health of the water system; for this reason, it can be used as an indicator of water quality. In particular, experimental observations show that proteins present in microorganisms fluoresce in the same region as the amino acid tryptophan. This tryptophan-like fluorescence (TLF) has been proposed in the recent past as an indicator of BOD while more recent studies are instead more oriented towards interpreting TLF as an indicator of a more generic bacterial presence.

Other contaminants of organic origin, such as hydrocarbons including polycyclic aromatic

Installation of the spectroscopic sensor on a marine drone and drone in action in the area of Genova (Italy) port

Data taken from a sensor based on ultraviolet fluorescence, installed in the port of Livorno in the framework of the project S4E (Safety & Security Systems for Sea Environment). The acquisitions show the temporal evolution of the presence of hydrocarbons in water probably due to fuel residues.



hydrocarbons (PAHs) and microplastics, can also be detected through their autofluorescence.

The sensors developed at IREA detect TLF, bacteria and other organic contaminants using autofluorescence in the UV region. Over the last few years, IREA researchers have designed several prototypes aimed at specific monitoring. These sensors have been used in various research projects and installed on buoys or marine drones.

In addition to pollutants of an organic nature, freshwaters and coastal marine waters can register the presence of inorganic substances, potentially harmful or relevant to monitor. These include, for example, nitrates and phosphates. More generally, water quality can be negatively affected by human activities, such as the use of agricultural fertilizers, wastewater discharge, atmospheric emissions, navigation and combustion processes.

In cases where the substances to be detected are not fluorescent or high specificity is required, Raman spectroscopy is a particularly suitable technique for the analysis of water samples.

Also in this case, IREA researchers designed and used Raman spectroscopy sensors implemented with jet waveguides, both for laboratory instrumentation and for prototypes to be used in the field for online and real-time measurements.

CONTACT

Gianluca Persichetti

Phone +39 081-7620644

persichetti.g@irea.cnr.it

COASTAL MARINE AREAS AND LAKES

Estimation of surface current and wind from SAR data in coastal marine areas and lake environment

Virginia Zamparelli, Gianfranco Fornaro, Giacomo De Carolis, Marina Amadori

In 2015, United Nations Member States provided a collection of 17 interlinked global goals, the Sustainable Development Goals (SDGs), designed to be a "blueprint to achieve a better and more sustainable future for all". Among these, Life Below Water is the 14th and plans to responsibly manage and protect all marine life around the world.

Oceans cover 71% of the earth's surface and are essential for making the planet liveable. Marine pollution, due for example to plastics released into the oceans, is endangering the life of fish and seabirds. Within this objective of the SDG, the prevention and reduction of marine and coastal pollution is essential.

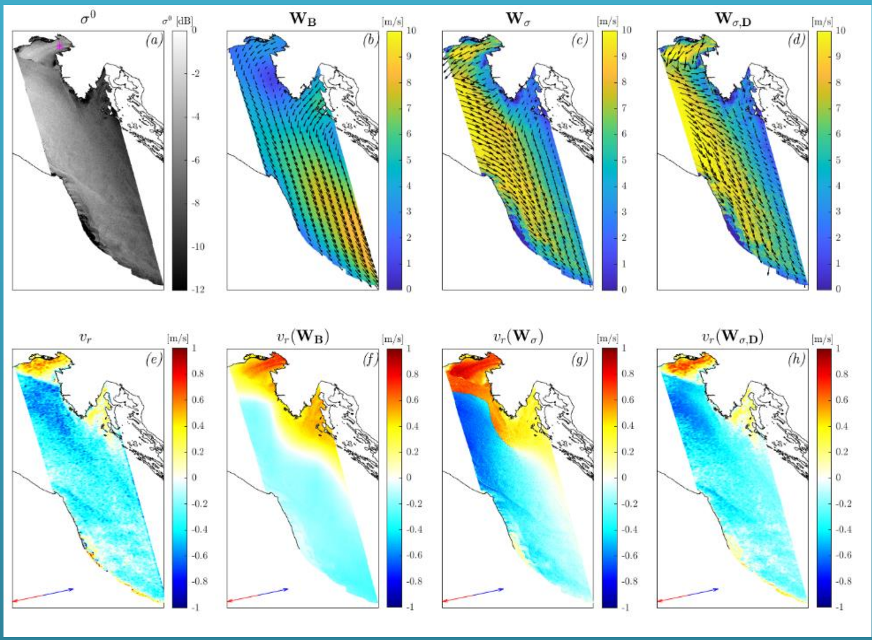
In this context, marine remote sensing plays a significant role thanks to notable technological growth. Satellites, especially, represent an essential instrument due to the synoptic acquisition potentialities. Among them, the Synthetic Aperture Radar (SAR), thanks to its systematic illumination capabilities (day-night and weather-independent), allows us to obtain high-resolution data, specifically useful for the analysis of marine variables.

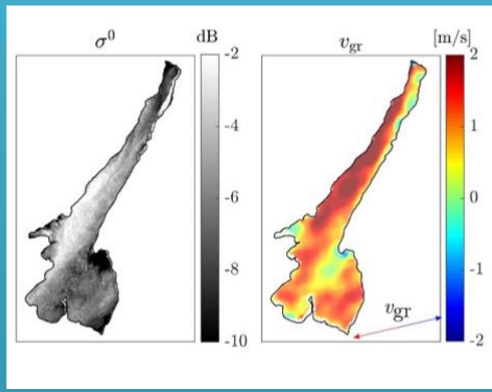
SAR is already a well-established instrument in the marine context, for example for marine pollution monitoring, such as oil spills, and nowadays it is becoming very useful for understanding marine phenomena affecting the sea surface, complementing the traditional use of optical or multispectral images.

Typical marine SAR remote sensing applications exploit the amplitude of the backscattered signal, such as for monitoring oil spills and sea ice. However, when the purpose is the extraction of quantitative parameters of the sea surface, the exploitation of the only SAR intensity is not sufficient for a direct measurement of sea currents. Conversely, the joint use of amplitude and phase information encoded in SAR images provides the means to estimate the parameters of interest. In particular, IREA researchers have developed an approach based on the estimation of the Doppler Centroid Anomaly (DCA) in order to monitor and estimate sea events.

Literature offers several examples of applications of SAR observations for estimating sea currents (intensity and direction), which mainly refer to test sites located in ocean areas or coastal regions characterized by intensive water mass movement. This characteristic allows easily separating, from a qualitative point of view, components associated with ocean dynamics from meteorological inferred sources. Conversely, the IREA research group focuses on the Mediterranean Sea, which is an area characterized by currents whose intensity ranges in a much more limited interval concerning the ocean case.

Recently, the IREA research group has investigated the potentialities of detecting near-surface wind fields using Doppler information combined with SAR backscattering in the coastal area around the Gulf of Naples and the North part of the coastal area of the Adriatic Sea. The test sites are interesting, both for





An example of the preliminary results obtained on Lake Garda. On the left it is represented the SAR amplitude image, while on the right the corresponding estimated the sea surface velocity map, obtained from the DCA map.

Obtained results for estimation of sea surface complex wind field through the combination of SAR backscatter and DCA information. Panel (a) represents the SAR amplitude, panel (b) is the wind obtained from European Centre for Medium Weather Forecating model, panel (c) is the wind estimation with integration of SAR backscatter, and panel (d) is the wind estimation with integration of both SAR backscattering and DCA. Panels (e) denote the radial component of the sea surface velocity, while panels (f)-(h) show the surface velocity relative to each wind estimation. In particular, the red and blue arrows on the bottom left of panels represents a motion toward (red) and away from (blue) the sensor, respectively.

their particular orography, since they are semi-enclosed basins largely surrounded by mountains, and for their characteristics of complex meteorological phenomena such as the Bora wind. The obtained results provide an improvement in wind field prediction, in terms of direction and intensity. As an example, one of the obtained results is reported in Figure 1.

Furthermore, thanks to the skills gained in the marine field, the IREA researchers investigated the possibility of extracting the water surface velocity in a challenging environment such as lakes. This is an innovative approach, considering SAR characteristics (synoptic coverage, fine spatial detail, and repeated regular sampling), compared to the ones exploiting the sensors commonly used in lakes. Nowadays, remote sensing has been widely used also to monitor lake water quality by providing maps of turbidity, chlorophyll, and water temperature. The most consolidated lake applications exploit visible and infrared wave band sensors to map water quality parameters, while quantitative information on wind and water velocity in lakes has been so far obtained only through sparse in situ measurements and numerical models.

For this innovative application, Lake Garda has been considered as a test case being a clear oligotrophic lake, thus allowing for neglecting turbidity and algal blooms that might affect the SAR signal. The lake is characterizes by a heterogeneous bathymetry and orography. Based on these considerations, a methodology validated in the marine coastal area of the Gulf of Naples and the Gulf of Trieste has been adopted. An example of the preliminary results is reported in Figure 2.

CONTACT

Virginia Zamparelli

Phone +39 081-7620629

zamparelli.v@irea.cnr.it

FISHERY

FishDataNet: supporting EU Common Fishery Policy

Martina Zilioli, Gloria Bordogna, Paola Carrara, Cristiano Fugazza, Simone Lella, Alessandro Oggioni, Paolo Tagliolato

Today, our seas and their rich biodiversity that the socio-economic fabric depends on, are facing many complex challenges, such as the effects of maritime activities, pollution (e.g. nutrient enrichment and contaminants, marine litter, including plastics and micro-plastics, underwater noise, etc.), and climate change (such as the spread of non-indigenous species).

These challenges affect also fishing and aquaculture, professions with a long tradition deeply rooted in our cultural heritage. In Europe, the impact of fishery on the marine environment and recovery of many fish stocks in the EU sea basins is based on a common policy called CFP (Common Fisheries Policy), a stable legislative framework for fisheries management. Over the last 50 years, CFP has been the basis for developing high standards for the conservation and management of living marine resources, as well as contributing to the protection of the marine environment. Along with other priorities, this policy is crucial to support the revitalisation of coastal communities and improve their economic prospects with more innovation and technology.

CFP is supported through scientific advice by the Data Collection Framework (DCF), a European action that has existed since 2000, for collecting data representing the status of resources and performance of fishery in EU sea basins. Under DCF, EU Member States collect data following national work plans and report annually on the CFP implementation. They coordinate their activities in regional coordination groups (RCGs) which may also prepare regional work plans; one of them is the Mediterranean and Black Sea RCG.

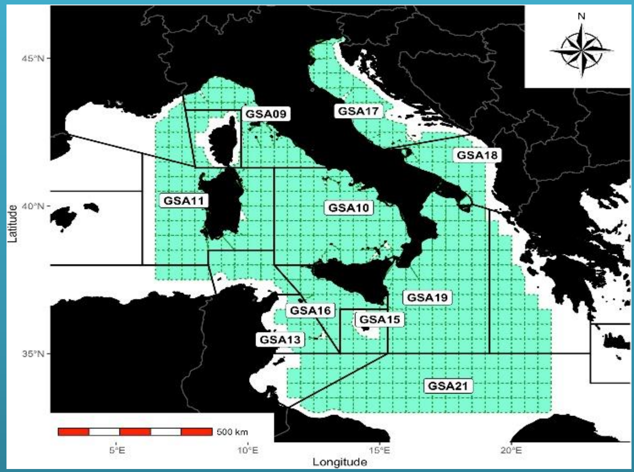
DCF is a mandatory legislative act (Reg 1004/2017) and aims at creating multi-annual standard data series in two European regions: A) Mediterranean and Black Sea; B) North and Baltic Sea, North-East Atlantic Ocean. To this aim, the European Commission reserves specific funds (FEAMP – Fondo Europeo per gli Affari Marittimi e la Pesca) that are ruled and delivered by EC-DG MARE.

Data collected within DCF (biological, economic and social) are obtained by means of either structured scientific campaigns or samplings on commercial activities in different sectors (aquaculture, transformation industry).

It is worth noticing that Italy is the European Member State with the greatest number of statistics sampling areas (called GSAs), so that DCF requires a greater implementation effort and coordination with respect to other countries. European funds are received by the Italian Ministry in charge (i.e. MASAF – Ministero dell'Agricoltura, della Sovranità Alimentare e delle Foreste), which must produce and store annual data series requested by calls of DG MARE and other Commissions for fishery management (FAO-GFCM, ICAAT).

DCF Regulation mandates the Ministry to create a

Public home page of FishDataNet (https://dcf-italia.cnr.it)



Geographic Sampling Areas of Italian seas, where 13 Operating Units collect national data for DCF

https://www.frontiersin.org/articles/10.3389/fmars.2022.824857/full

safe national database to host and manage national data series. Since 2018, IREA has been in charge of developing, upgrading and managing the Information System for MASAF (hosted by CNR servers).

The system, called FishDataNet, Portale Nazionale Dati Alieutici (https://dcf-italia.cnr.it), offers to the public a website describing the national data collection activity and driving to specific sections on participants, documentation, and how to request data. An intermediate layer, for reserved users only, manages the database, allowing us to create and modify controls on structures and data consistency with respect to end-users specifications; to upload, update and search data; to export datasets to be delivered to end-users. An inner layer hosts a relational DataBase Management System for storing aggregated and detailed data as well as national annual reports.

Today the system is populated by structured historical series of data in the range 2017-2021 (data from 2002 are going to be added shortly).

FishDataNet users, who can access the non-public functions of the system, are the representatives of Italian Operating Units, collecting, processing and uploading data of the Italian GSAs; domain experts who support MASF in meeting requests from DG MARE and other end-users; the national correspondents, as well as MASAF clerks, and system administrators.

Maintaining and upgrading FishDataNet represents an institutional activity that enables uploading the annual data series and reports. The system is an operational service for a national Ministry, necessary to meet a Community Regulation: it must be extremely reliable and each modification must be properly tested before adoption.

Nevertheless, some research activities are under development. One of them is improving data and system FAIRness, i.e. fostering findability, access, reuse and data interoperability, beyond restrictions due to data sensitivity and terms of access in the Regulation. This is encouraged by the fact that DCF is a data collection financed by public funds, and data accessibility and reuse allow us to meet other EU Directives and policies (such as MSFD, agreement FAO, and INSPIRE).

One more research direction is represented by using Knowledge Graphs to model knowledge representation. In fact, DCF data models change in time (there is a pool of heterogeneous csv files and dbms relations, which ask for a continuous adaptation to novel specifications), and domain users are scarcely able to represent their knowledge by entities allowing to create permanent structures for data.

CONTACT

Paola Carrara

Phone +39 02-23699295

carrara.p@irea.cnr.it

RESEARCH INFRASTRUCTURES

Methods for Environmental Data Management in Semantic Research Infrastructures

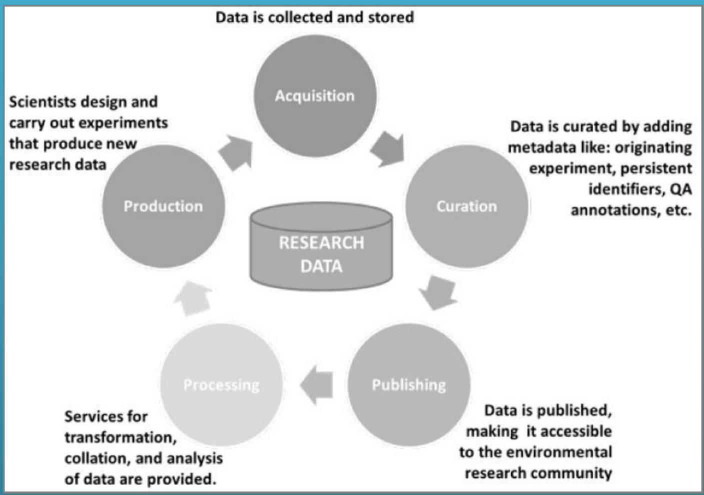
Gloria Bordogna, Sabatino Buonanno, Paola Carrara, Francesco Casu, Cristiano Fugazza, Adele Fusco, Michele Manunta, Alessandro Oggioni, Paolo Tagliolato, Giovanni Zeni, Martina Zilioli

Efficient and effective environmental data management poses a critical challenge to our planet sustainability, resilience, and conservation in an era marked by climate change. The proliferation of geospatial data sources, both in-situ and remote, the complexity of environmental interactions, and the necessity for informed decision-making demand advanced solutions to support decision-makers using digital information management methods.

Semantic research infrastructures are an essential component of an effective and efficient decision support system, as they enable the acquisition, integration, analysis, and interpretation of environmental data, especially those with geographic references. These infrastructures represent an intelligent environment capable of collecting, aggregating, and analyzing heterogeneous data, creating an interconnected information ecosystem. They rely on Semantic Web methods, which focus on extracting and understanding the meaning of data rather than merely manipulating them. In geospatial contexts, data is enriched with location information, enabling detailed analysis of the correlation between different environmental variables and their geographical locations, and facilitating the identification of areas with possible anomalies deserving of further investigation. For example, by integrating climate data, biodiversity data, and anthropogenic impact data, it is possible to understand better the effects of climate change on specific ecosystems. This is achieved by organizing data through ontologies and/or knowledge graphs, which structure the conceptual representation of data by capturing relationships among entities and defining a common vocabulary understandable by both machines and humans. This approach offers a feasible solution to the challenges related to data heterogeneity, interoperability, and the comprehension of shared concepts across different research and application domains, facilitating multidisciplinary and interdisciplinary data understanding and impact assessment.

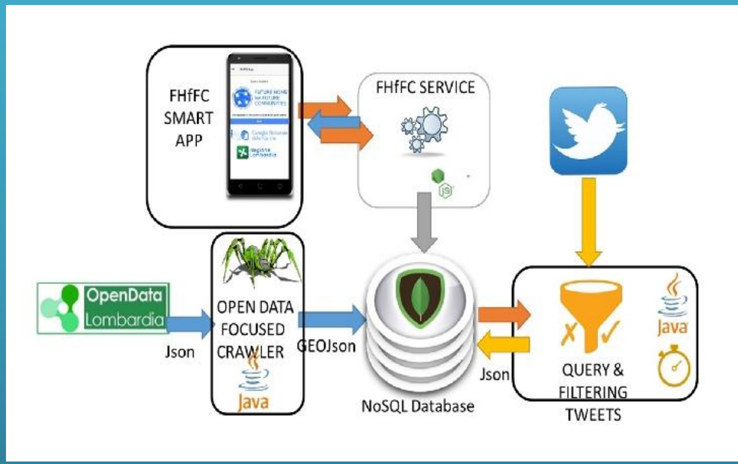
The integration of environmental biodiversity observations poses a specific challenge for semantic infrastructures. It requires using standardized measurement protocols, adopting shared formats and, most importantly, utilizing computational tools that unambiguously define the meanings of the processed data. In this research domain, simple harmonizing actions are insufficient, especially when considering data contributed by volunteers and citizens through citizen science methods as well as data stored in historical archives and libraries. In such cases, semantic research infrastructures entail enriching the explicit attributes of data through, for example, descriptions of measurement quality and collection and manipulation methodologies. In this way, we can compare data from diverse sources, creating reliable automated processes for aggregating primary data, resulting in indices whose construction is carefully traced and justified.

A key role is played by standardized metadata, which



The research data lifecycle model of the ENVRI RM. ENVRI is a community of Environmental Research Infrastructures, projects, networks and other diverse stakeholders interested in environmental Research Infrastructure matters

Reproduced from ISPRS Int. J. Geo-Inf. 2017, 6(11), 354



Components of the platform SO-GREAT (Smart cOmmunity-based Geographic infoRmation rEtrievAl SysTem) that offers heterogeneous georeferenced data about both authoritative resources and services offered by volunteers via an app

are crucial for aggregating environmental data and assessing Essential Variables frameworks (e.g. Essential Biodiversity Variables - EBVs, Essential Climat Variables - ECVs, and Essential Ocean Variables - EOVs). By providing information in three dimensions of variables (space, time, and taxonomy) and their related attributes (extent, resolution, and units of measurement), they support integration and exchange processes, facilitating data retrieval as well as the reuse of data already available.

The development of methods for semantic research infrastructure implementation has fundamental implications at the European level within the ENVRI community (https://envri.eu/), consisting of European Environmental Research Infrastructures. Through the provision of their services (especially in the distribution of observational data), they play a crucial role in improving the understanding of the Earth system. While most of them were originally established independently to serve specific environmental research areas, the interconnected nature of the Earth system has led to pursue a better collaboration and transcending boundaries between disciplines and domains, sharing methods and tools in search of common solutions, thus avoiding unnecessary costs and duplication of efforts. However, this necessitates an effort toward interoperability, which cannot be limited to data exchange formats but must extend to the mutual understanding between disciplines, i.e., semantics.

IREA, which participates in ENVRI through EPOS (European Plate Observing System) and eLTER RI (Long-Term Ecosystem, critical zone, and socio-ecological Research Infrastructure), has made significant contributions to the methodologies and tools for the creation and management of semantic research infrastructures. For example, they have proposed suites of open-source software like GET-It and the metadata editor EDI. Furthermore, recognizing that geospatial metadata is often non-standardized, resulting in highly heterogeneous descriptions of the same environmental entities, thus hindering the straightforward identification of available data, IREA researchers have proposed "semantic lift" methodologies, which enable the ex-post attribution of semantics to metadata.

In conclusion, semantic research infrastructures represent a crucial advancement in methodologies for environmental data management, aligning with the vision of creating the ENVRI community. IREA is committed to experimenting with methods and techniques for realizing semantic infrastructures through the use of ontologies and approximate reasoning methods, enabling intelligent sharing of environmental observations and a deeper understanding and more efficient management of environmental impacts on the Earth system.

CONTACT

Paola Carrara

Phone +39 02-23699295

carrara.p@irea.cnr.it

NATURAL AND

ANTHROPIC RISK

Natural and anthropic risks due to earthquakes, volcanic eruptions, landslides, floods, urbanization, and anthropic activities raise significant challenges to communities and their sustainable development. Monitoring these risks is crucial for early warning, response planning, mitigation and restoration strategies.

IREA is engaged in significant research and technological transfer activities in the area of monitoring the territory using satellite/aerial/drone radar sensors and techniques for the identification and evaluation of risk factors (seismic, volcanic, hydrogeological, anthropic) and the surveillance of built environment and infrastructures.

IREA is a Center of Competence of the Department of Civil Protection for the ground deformation monitoring associated with natural and anthropic hazard phenomena detected through Differential Synthetic Aperture Radar Interferometry (DInSAR), a satellite-based radar technique that measures ground deformation with high precision by comparing radar images acquired at different times. In this context, IREA generates maps of displacement induced by the main seismic events at a national and international level. Furthermore, IREA researchers have recently developed and implemented an automatic service for the systematic generation of coseismic displacement maps at a global scale.

IREA researchers have also implemented an automatic operational service for monitoring crustal deformations in active volcanoes, which uses a methodology completely developed at IREA and widely used internationally that allows the study of the temporal evolution of the deformational phenomena. Through this implemented system, IREA monitors the crustal deformations of the principal active Italian volcanoes, such as the Campi Flegrei Caldera, Vesuvius, the island of Ischia, Etna, Stromboli and Vulcano, and provides monthly updates to the Civil Protection Department.

Advances in satellite remote sensing technologies, based on Synthetic Aperture Radar images, have even permitted us to monitor localized deformation affecting single buildings in urban areas, transport infrastructures and archaeological sites.

Multi-temporal SAR interferometry allows the analysis of large areas, identifying ground displacements, and studying the phenomenon evolution on long-time scales; therefore, this methodology finds an application in detecting and monitoring instabilities affecting both terrain slopes and man-made objects.

IREA researchers have developed an innovative data processing methodology, known as SAR Tomography, able to achieve a three-dimensional reconstruction of the scene under investigation by exploiting multipass SAR data. This “radar scanner” from space, when exploiting very high-resolution SAR data, can monitor a single facility and follow its deformation by making the methodology well-suitable to urban areas and landslide monitoring.

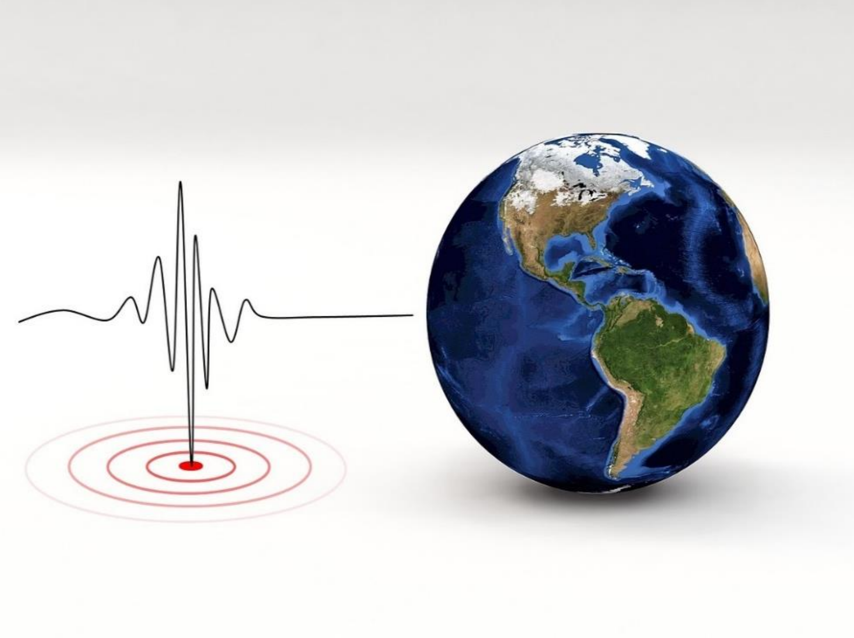
Moreover, research activities are ongoing at IREA to improve the performance of approaches, based on the joint exploitation of radar and optical data for mapping flood events that, often exacerbated by climate change, threaten both urban and rural areas.

In recent years, given the exponential increase in satellite data, thanks to the availability of new constellations of advanced sensors, machine learning approaches and artificial intelligence are acquiring an increasingly important role in research activities.

The satellite-derived (radar and optical) information coupled with in situ measurements has allowed IREA researchers to develop, implement and demonstrate the effectiveness of modelling approaches for imaging of the inside of volcanoes and characterization of seismogenic faults.

IREA also has considerable expertise in using in situ diagnostic techniques for infrastructure and building monitoring. In particular, the methodologies of data processing from ground penetrating radar developed at IREA represent issues of great relevance for safety. They consent to obtain detailed information on the analyzed asset or the monitored structures and to detect any risk factors through non-invasive monitoring. Moreover, they allow us to detect, locate and determine the extent and shape of buried objects. This made it possible to identify, in November 2019, the plan of a small Doric temple from the 5th century B.C. near the walls of the ancient city of Paestum in Campania, a monument defined as a "jewel of late-archaic Doric architecture", and its location approximately at one meter underground.

EARTHQUAKES



Ground deformation monitoring in seismic events by using satellite radar techniques

Francesco Casu, Simone Atzori, Paolo Berardino, Manuela Bonano, Sabatino Buonanno, Claudio De Luca, Adele Fusco, Michele Manunta, Fernando Monterroso, Giovanni Onorato, Yenni Lorena Belen Roa, Pasquale Striano, Muhammad Yasir, Giovanni Zeni, Ivana Zinno, Riccardo Lanari

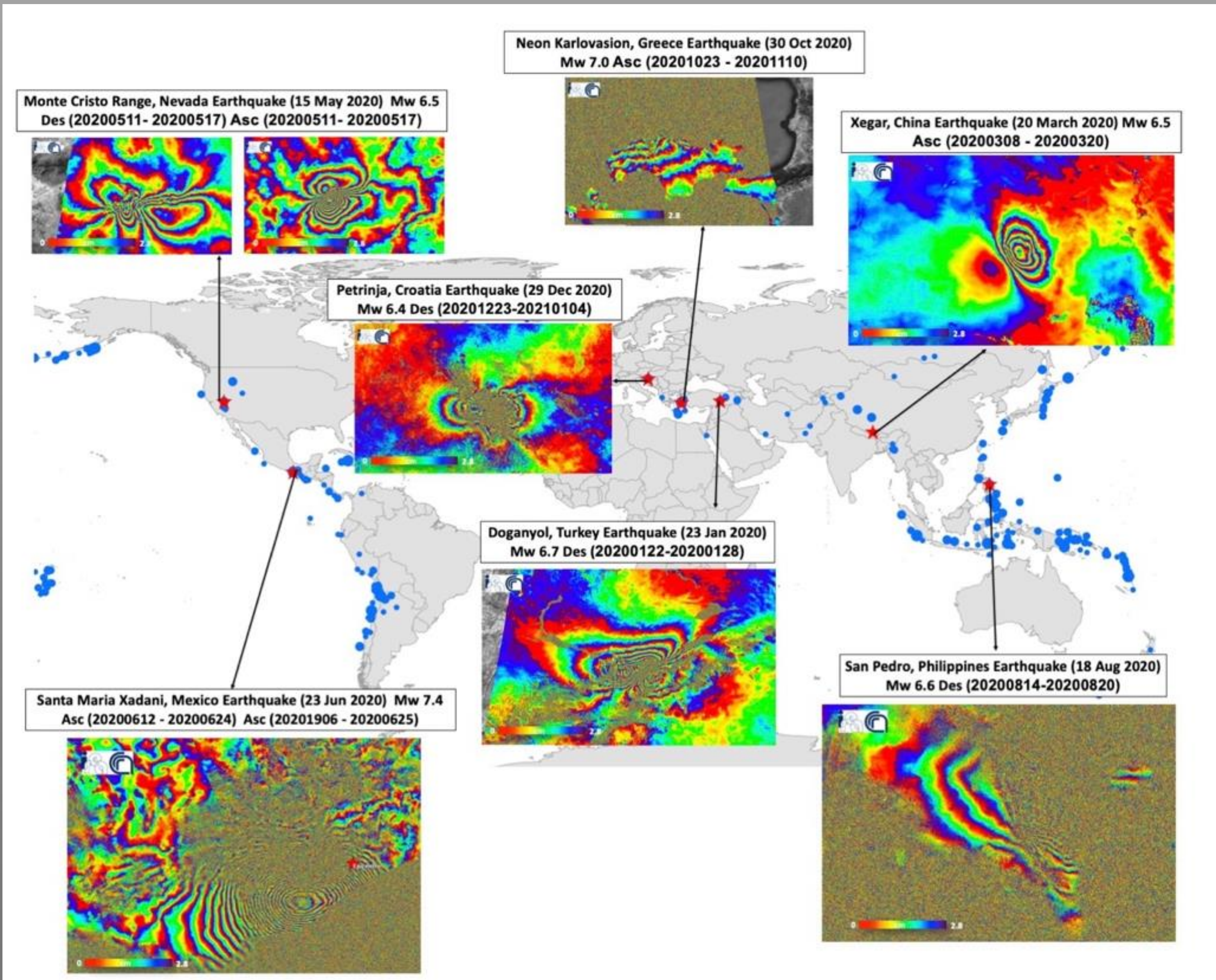
Being an active microwave Earth Observation (EO) technique, space-borne Differential Synthetic Aperture Radar Interferometry (DInSAR) represents a very powerful tool for the estimation of ground deformation, thanks to its characteristics of large spatial coverage, cost-effectiveness, and all-weather imaging capability. Since the 1992 Landers (California) earthquake, which was the first detected by interferometric radar images acquired on repeat passes of the ERS-1 satellite, the DInSAR technique has been a viable means of studying earthquakes with observations independent of seismology. In particular, DInSAR interferograms provide information that can be used to model the seismogenic fault that ruptured during an earthquake, thus improving our knowledge of the causative earthquake source.

In this context, acting as a Center of Competence for the Italian Department of Civil Protection (DPC), IREA has provided DInSAR co-seismic displacement maps for the major earthquakes that have occurred on the Italian territory since 2009.

Recently, the Sentinel-1 (S1) mission, operating since 2014 and belonging to the European Copernicus program, has been acting as a game changer in the EO scenario and natural hazard monitoring.

The Sentinel-1 constellation is composed of two twin satellites operating in the C-band (the second satellite operated between 2016 and 2021), allowing systematic repeat observations down to 6 days in selected areas of the globe (for instance, the entire Europe) and image ground swaths of about 250 km wide, thus providing operational support for many scientific and commercial activities, such as natural hazard investigations. In addition, the S1 constellation is characterized by an “orbital tube” that has about a 200m nominal diameter and very accurate orbital information. The S1 constellation is therefore particularly suitable for DInSAR applications to detect ground deformation in seismically active regions. Moreover, the short repeat period ensures a quick response in the case of seismic events and fosters the generation of interferograms with good interferometric quality, even if they are relative to large areas. These characteristics, along with S1’s global coverage and free and open access data policy, have lowered the barrier to accessing DInSAR data and are continuously increasing the data flow that is supplied all over the Earth.

Thanks to the S1 characteristics, IREA recently developed and implemented an automatic service for the systematic generation of S1 DInSAR co-seismic displacement maps at a global scale, see Figure. The S1 short revisit time and its global spatial coverage allow us in principle to generate any possible co-seismic interferogram relevant to every earthquake capable of causing measurable surface deformation.



Pictorial representation of the DInSAR products that are routinely generated at a global scale every time an earthquake capable of causing measurable surface deformation occurs

The service is triggered by the most significant (according to a set of defined thresholds) seismic events registered by the online global earthquake catalogues, such as those provided by the United States Geological Survey (USGS) and the Italian National Institute of Geophysics and Volcanology (INGV). Then, after automatically querying and retrieving the S1 data from the Copernicus catalogues, the service generates pre-, co-, and post-seismic deformation maps.

Finally, the retrieved information is stored and organized in a global DInSAR earthquake database that is openly available to the Solid Earth community through the European Plate Observing System (EPOS) Research Infrastructure. This allows the EO community to obtain co-seismic DInSAR displacement maps and related information in a short time frame and nearly anywhere in the world, thus significantly improving the capability for studying the seismic zones at a global scale.

CONTACT

Francesco Casu

Phone +39 02-23699275

casu.f@irea.cnr.it

EARTHQUAKES

Earthquakes from space: how and what

Filippo Accomando, Andrea Barone, Raffaele Castaldo, Vincenzo De Novellis, Francesco Mercogliano, Susi Pepe, Maddalena Perrini, Giuseppe Solaro, Pietro Tizzani, Andrea Vitale

Currently, about 20,000 earthquakes are recorded in the world every day, some of which are characterized by high seismic energy with significant destructive potential. In particular, in the areas exposed to a medium-high seismic risk, these events can generate victims and cause damage to infrastructures and the built environment. For this reason, the study, knowledge and monitoring of seismically active areas are now a priority of the international political agenda. This is relevant not only for earthquake destructive effects mitigation but also for a correct interpretation, from a scientific point of view, of the rupture mechanism along the causative faults and the propagation of seismic waves towards the Earth's surface.

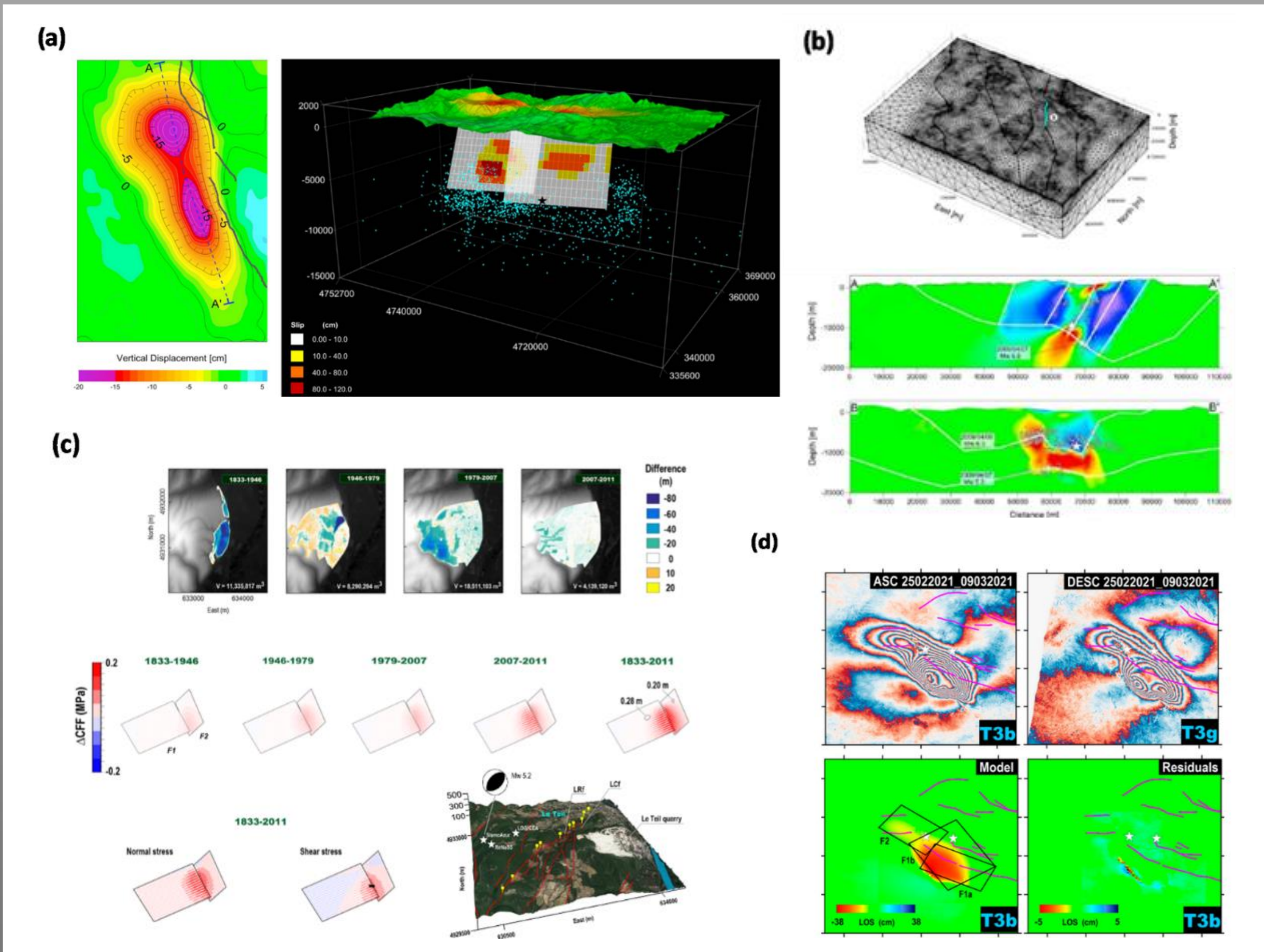
In this context, the increasing development of observation technology, and in particular the satellite-based one, has made it possible to improve the knowledge on seismic risk, making it possible to remotely observe the surface deformation induced by a seismic event, follow its potential evolution in time and space, and generate reliable models of the seismogenic faults.

In recent years, at IREA the research efforts have been focusing on the detection, localization and characterization of seismogenic faults through the joint data processing of surface deformation data obtained by InSAR and GPS.

These geodetic data can provide important constraints on fault geometry, its slip distribution and size. For this reason, in the last few years many researchers have developed robust and semiautomatic methods for inverting suitable models to infer the source type and geometry from surface deformation. Most of these methods use elasticity theory and a trial-and-error approach to find geologically plausible deformation models fitting the major features of the observed deformation field. Significant literature has systematically searched through a large set of feasible models, comparing the model predictions to the data and choosing the model that minimizes the misfit.

The approaches developed at IREA have been applied in various contexts to study earthquakes with different features. For instance, the Amatrice Seismic sequence, which occurred on 21st August 2016 along the Mt. Vettore fault, was imaged by using InSAR satellite data and then modelled through analytical inversion techniques (see Figure, panel a). This event revealed two North-NorthWest/South-SouthEast striking surface deformation lobes that were interpreted as the effect of two distinct faults or the rupture propagation of a single fault with a maximum slip of about 90 cm occurring at 5–7 km depth.

IREA researchers also investigated the stress and strain changes due to the L'Aquila 2009 earthquake and its main aftershock simulating the blocks kinematic, generating the fault model of the structures involved in the sequence thanks to the exploitation of geological/seismological information



Several models of seismogenic faults estimation for different earthquakes

Panel A reproduced from Geophys. Res. Lett., 2016, 43(24), 12389, CC-BY-NC-ND license (https://creativecommons.org/licenses/)
Panel B reproduced from Journal of Geophysical Research: Solid Earth, 2018, 123(5), 4193 (https://doi.org/10.1002/2017JB014453)
Panel C reproduced from Commun Earth Environ, 2020 1(20), CC BY license (https://creativecommons.org/licenses/by/4.0/)
Panel D reproduced from Remote Sens. 2021, 13(17), 3410 - CC BY license (https://creativecommons.org/licenses/by/4.0/

(panel b). The developed model takes into account the 3-D crustal heterogeneities, the complexity, and the curvature of the investigated fault system.

Another significant example is concerned with the understanding of the relationship between a seismic event and human operations, which can produce increases in stress load and degradation of strength on nearby active faults by raising the potential for failure. Panel c shows the estimate of the rupture geometry and source directivity of the Le Teil earthquake (7th November 2019, France) based on differential Interferometric Synthetic Aperture Radar and seismic data.

Finally, panel d shows a geodetic model for the Thessaly seismic sequence (Greece, March 2021) by using InSAR technique on Sentinel-1 images. Surface deformation from three major events was successfully detected, revealing previously unknown blind faults. In this case, geodetic inversions were consistent with the activation of distinct North-East-dipping and South-West-dipping normal faults associated with different events. Coulomb stress transfer analysis and pore pressure modelling showed a domino effect in the sequence's space-time evolution. Since missing information about historical earthquake records and surface features complicates seismic hazard estimation, InSAR data were crucial in constraining rupture characteristics.

CONTACT

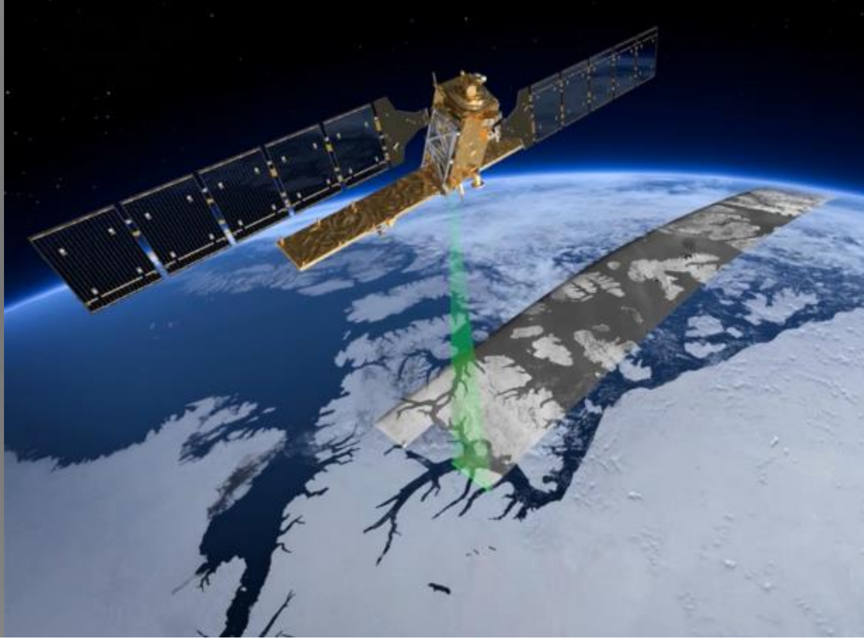
Giuseppe Solaro

Phone +39 081-7620631

solaro.g@irea.cnr.it

GROUND

DEFORMATIONS



Large scale ground monitoring analysis

Claudio De Luca, Giovanni Onorato, Federica Casamento, Francesco Casu, Sabatino Buonanno, Adele Fusco, Michele Manunta, Fernando Monterroso, Pasquale Noli, Manuela Bonano, Francesco Poggi, Muhammad Yasir, Giovanni Zeni, Ivana Zinno, Riccardo Lanari

Advanced DInSAR (A-DInSAR) techniques are based on large, multi-temporal stacks of SAR images to retrieve the temporal evolution of the ground displacements with centimeter to millimeter accuracy.

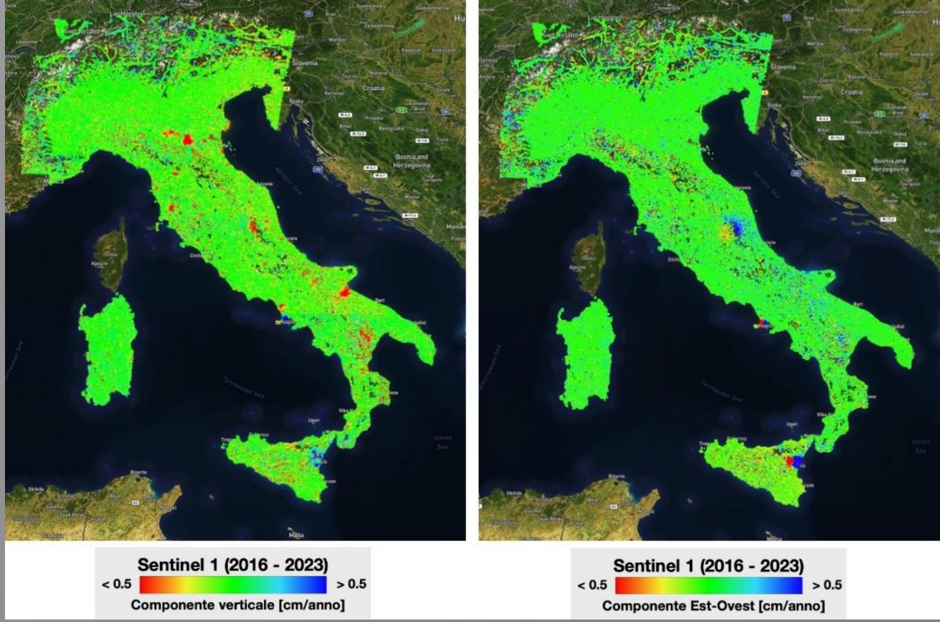
A peculiarity of the satellite A-DInSAR analysis is the capability to monitor large areas on the ground with a relatively high spatial measurement density and in a non-invasive way, thus allowing economic saving. It provides a systematic acquisition to guarantee continuous updating of the computed deformation time series, as well as the investigation of the past deformation phenomena by exploiting the SAR image historical archives. Moreover, in the last decades, the satellite DInSAR technology has widely demonstrated its crucial role in civil protection activities within emergency scenarios, and for what concerns research and commercial purposes.

Since the early 90s, the A-DInSAR has been based on medium-resolution C-band data acquired by the ERS-1/2, Envisat and Radarsat-1 SAR sensors. At a later time, the A-DInSAR took a step forward with the advent of very high-resolution X-band data obtained thanks to the TerraSAR-X and COSMO-SkyMed systems. A further, very significant improvement was presented by the launch of the Sentinel-1 twin satellites of the European Copernicus Program, equipped with C-band sensors. The Sentinel-1 sensors have improved the existing data acquisition performance in terms of area coverage, revisiting time and data throughput, thus increasing the A-DInSAR deformation monitoring capability. Moreover, Sentinel-1 implements a free and open access policy allowing the user community to enlarge enormously the application contexts.

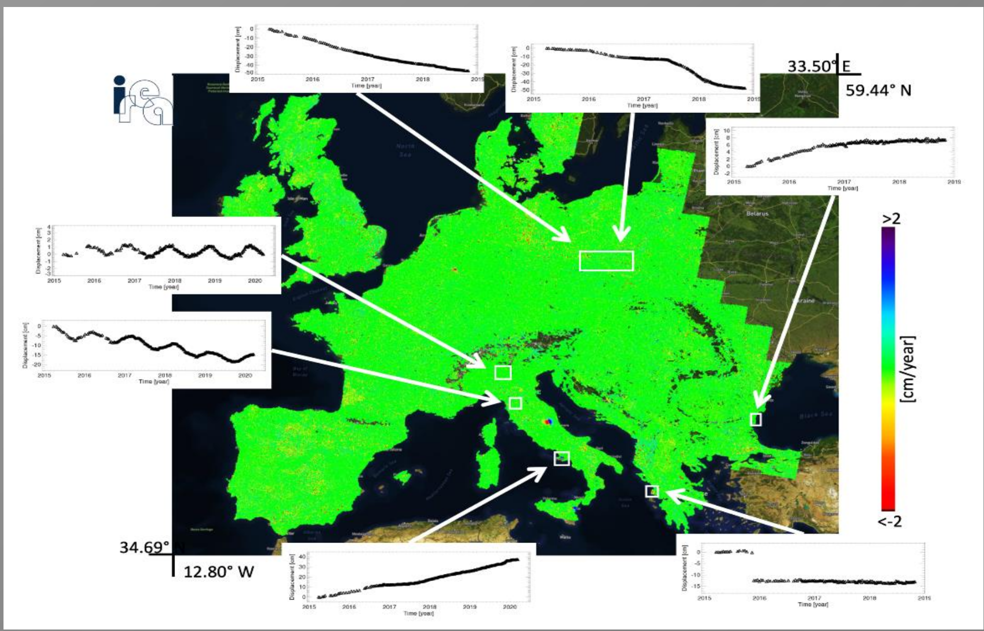
However, the availability of such a huge data stream has led to a drastic increment in the data processing load and complexity. This issue represents a limitation for the effective DInSAR exploitation, not only for the Sentinel-1 data but also for extensive processing of the available large C-band (ERS-1/ERS-2/ENVISAT) ESA archives. To avoid this severe bottleneck, in the last years, new computing solutions have been identified and implemented, which exploit powerful processing facilities as well as advanced processing algorithms and tools.

Thanks to these developments, A-DInSAR has moved from local deformation studies, typically a few tens of square kilometers, to regional, national up to continental scale.

In this context, the IREA researchers have implemented, since 2015, a nationwide A-DInSAR-based Ground Motion Service (GMS) with the Italian Ministry of Economic Development (MiSE), now the Italian Ministry of Ecological Transition (MASE). In Figure 1 shows the results of the above-mentioned institutional activity, in particular the vertical and horizontal mean deformation velocity maps obtained by the ground deformation time series retrieved over the entire Italian territory.



Vertical (left) and Horizontal (right) mean deformation velocity maps (cm/year) at national scale, geocoded and superimposed on an optical image of Italy. The deformation components have been retrieved by processing the whole S1 data acquired from ascending and descending orbits



Mosaicking of the LOS mean deformation velocity maps (cm/year), geocoded and superimposed on an optical image of Europe (Mapbos Satellite Streets source). The white rectangles identify the areas where the deformations time series plots are shown

Moreover, the IREA researchers also performed an experiment to demonstrate the potentiality of the A-DInSAR analysis at a continental scale by processing the entire S1 image archives collected from March 2015 to September 2018. This study has represented a precursor of the European Ground Motion Service (EGMS) of the European Environment Agency (EEA). For this analysis, we processed 175 Sentinel-1 frames, each with an average number of SAR images of about 400. Globally, we used almost 72000 SAR images covering a whole area of about 4.500.000 km2. A mosaicking of the Line-of-Sight mean deformation velocity maps retrieved for each processed Sentinel-1 frame, is reported in Figure 2. This A-DInSAR processing was completed in six months and at relatively low computing costs of about 60 kEUR.

Generating interferometric products at this scale means the possibility to access an unprecedented amount of results containing value-added information potentially groundbreaking. The availability of spatially dense deformation time series over such large areas paves the way for new types of analyses and interpretation of such data. Moreover, the presented results clearly demonstrate that IREA algorithms, which are essentially based on a Cloud Computing implementation of the Parallel Small BAseline Subset (P-SBAS) processing chain, are suitable for massive and automatic monitoring at national and continental scales.

CONTACT

Claudio De Luca

Phone +39 081-7620638

deluca.c@irea.cnr.it

GROUND DEFORMATIONS

Future investments for the L-band satellite missions

Claudio De Luca, Giovanni Onorato, Paolo Berardino, Francesco Casu, Carmen Esposito, Michele Manunta, Manuela Bonano, Yenni Lorena Belen Roa, Marianna Franzese, Antonio Natale, Stefano Perna, Francesco Poggi, Pasquale Striano, Riccardo Lanari

In the last decades, the effectiveness of the satellite DInSAR technology for ground deformation analysis and its crucial role in an emergency scenario has been widely demonstrated, thus pushing space agencies to develop new space-borne SAR missions and infrastructures.

In particular, important investments in the development of L-band (i.e., operating with about 23 cm wavelength) SAR systems are ongoing, with the forthcoming missions of ESA (ROSE-L), JAXA (PALSAR-3) and NASA-ISRO (NISAR), as well as the already operating SAOCO, M-1 and PALSAR-2 systems.

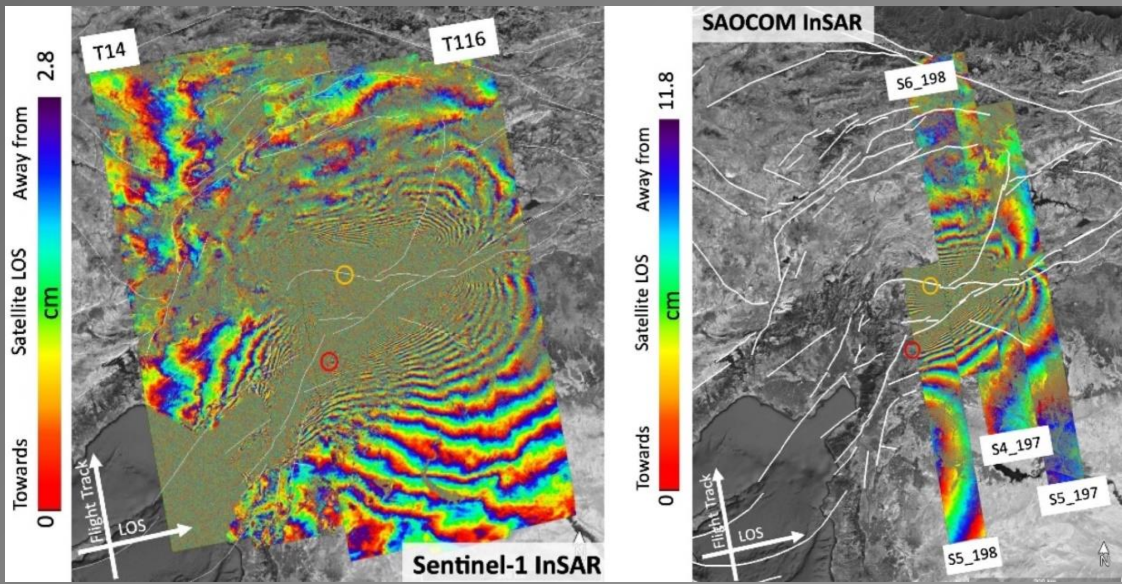
With respect to the usually deployed C-Band (i.e., operating with about 5 cm wavelength), the use of L-band differential interferograms allows significant advantages. The first one is the possibility of using in a more reliable way multi-temporal images SAR images, thus ensuring a longer time and larger spatial coverage of the scene under investigation. Secondly, at the cost of the lower sensitivity (minimum deformation detectable with respect to the X-band), it is simpler to observe large ground deformations.

Figure 1 shows the interferometric analysis of the surface deformation relevant to the February 2023 South-East Turkey and Northern Syria Mw 7.8 (red circle) and 7.5 (yellow circle) seismic events, carried out by exploiting C-band Sentinel-1 (top image) and images. In particular, the L-band interferograms, compared to the C-band ones, demonstrate the capability of the L-band technologies to reduce the fringe rate, which is particularly effective for the detection and post-event assessment of rapid deformations characterizing several geohazards such as earthquakes, landslides and motion in volcanic areas.

Finally, it is very important to highlight the improvement, in terms of the final measurement points number that we can obtain, particularly on vegetated areas, through a combined exploitation of the Parallel Small BAseline Subset (P-SBAS) processing chain and the L-band spaceborne SAR images.

Figure 2 shows the different performance between the SAOCOM-1 and Sentinel-1 A-DInSAR analysis retrieved by processing the two SAR datasets over the Tuscany region (Italy) by considering the same temporal range (from 2020 to mid 2023) with the P-SBAS approach. It is evident how the area detected by the SAOCOM-1 dataset (see the red footprint in Figure 2 at the centre of the picture) is characterized by a significantly denser ground coverage compared to the (C-band) Sentinel-1-based DInSAR analysis.

Co-seismic DInSAR interferograms of the February 2023 South-East Turkey and Northern Syria Mw 7.8 (red circle) and 7.5 (yellow circle) seismic events obtained through Sentinel-1 (top) and SAOCOM-1 (bottom) SAR image analysis.



Ground coverage differences between the Sentinel-1 and SAOCOM-1 DInSAR results of the P-SBAS analysis relevant to the Tuscany (Italy) region.

CONTACT

Claudio De Luca

Phone +39 081-7620638

deluca.c@irea.cnr.it

VOLCANOES

Monitoring of volcano ground displacements via spaceborne and airborne radar techniques

Francesco Casu, Paolo Berardino, Manuela Bonano, Teresa Bortolotti, Sabatino Buonanno, Federica Casamento, Federica Cotugno, Claudio De Luca, Prospero De Martino, Federico Di Traglia, Alessandro Di Vincenzo, Carmen Esposito, Marianna Franzese, Adele Fusco, Flora Giudicepietro, Giovanni Macedonio, Michele Manunta, Fernando Monterroso, Antonio Natale, Pasquale Noli, Giovanni Onorato, Francesco Poggi, Yenni Lorena Belen Roa, Stefano Perna, Pasquale Striano, Muhammad Yasir, Giovanni Zeni, Ivana Zinno, Riccardo Lanari

Monitoring crustal deformation in active volcanic areas often represents a not easy task. In this sense, remote sensing can make the difference, compared to in-situ techniques, due to its capability to provide dense measurements on a large spatial scale and at a relatively low cost. In particular, Differential Synthetic Aperture Radar Interferometry (DInSAR) is becoming one of the usual techniques to measure ground deformation independently from atmospheric conditions and with high accuracy.

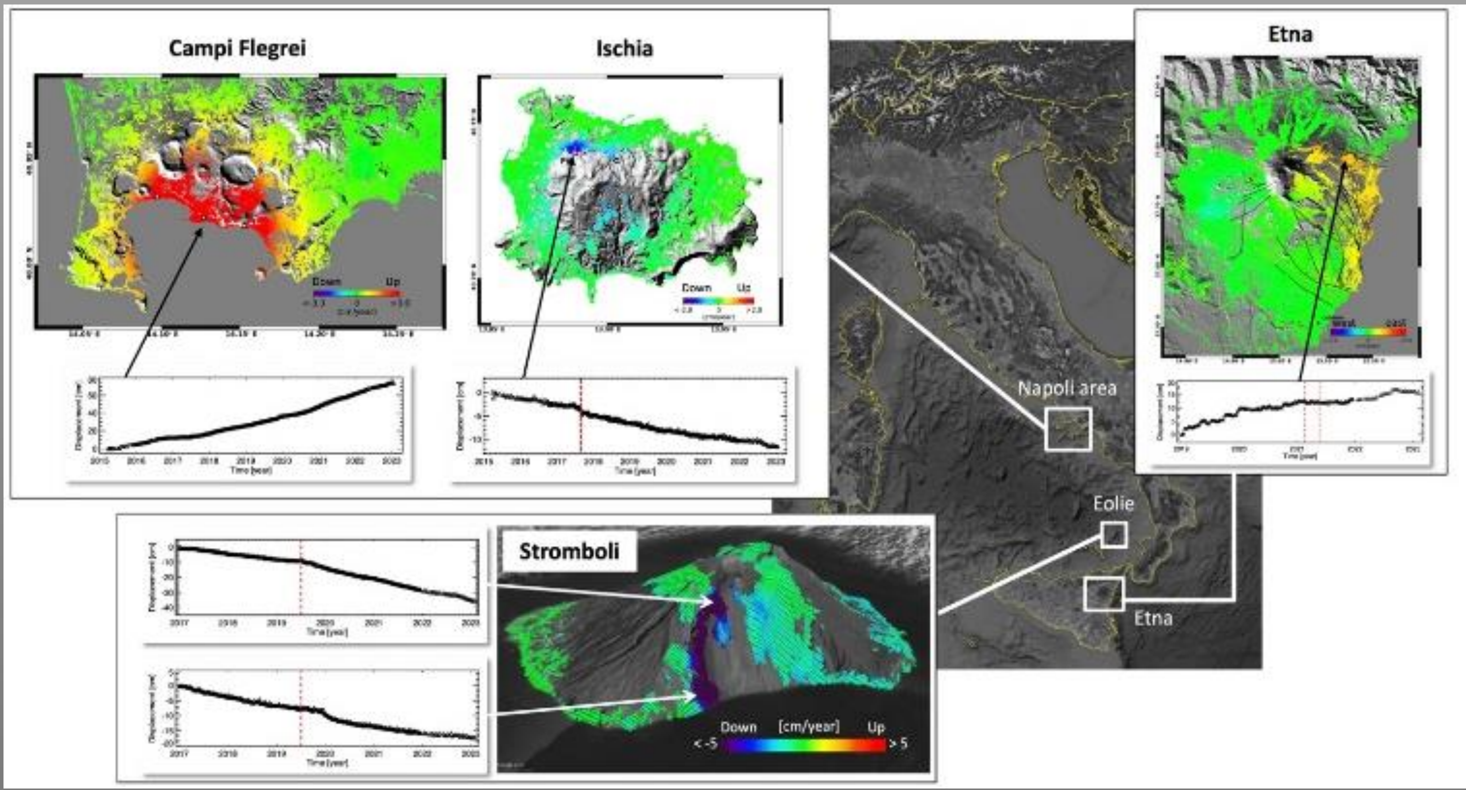
The increasing diffusion of the use of DInSAR is also due to the recent large availability of huge and easily accessible SAR data archives. In particular, since late 2014, the Copernicus Sentinel-1 constellation has been globally providing SAR data with a repeat-pass frequency that, in the best cases, is 6 days.

It is clear, therefore, that with such a huge, global, constant and reliable data availability, it is possible to exploit the DInSAR technique for monitoring purposes, such as those related to the measurements of the ground motion in volcanic areas.

In this framework, IREA has implemented an operative service for monitoring the crustal deformation in active volcanoes through the use of the DInSAR techniques applied to Sentinel-1 data. The designed system is fully automatic and the process is triggered by the availability, for every monitored volcanic site, of new SAR data in the Sentinel-1 catalogues acquired from both ascending and descending passes. The data are then ingested and processed, per each orbit, through the well-known Parallel Small BAseline Subset (P-SBAS) DInSAR technique in order to retrieve the displacement time series relevant to the investigated volcano. The so-retrieved Line of Sight (LOS) measurements are then combined to compute the Vertical and East-West components of the deformation, which are directly understandable by the end users.

Although the service is meant to serve the Italian DPC, it is based on widely used Information Technology standards so that it can be easily exported to several computing environments, such as those made available through the Copernicus DIAS or the Amazon Web Services (AWS), as well as it can be extended to include other volcanic areas on Earth.

The service has been developed by IREA within its duties as the Centre of Competence of the Italian Department of Civil Protection (DPC) for volcano areas studying and monitoring. Accordingly, the



Pictorial representation of the ground displacement measurements that are routinely generated for the main Italian active volcanoes, by processing data acquired by the Sentinel-1 Copernicus constellation

implemented system is currently operative for monitoring the main active Italian volcanoes, such as the Campi Flegrei caldera, Mt. Vesuvius, Ischia, Mt. Etna, Stromboli, and Vulcano, see Figure. For all these sites, IREA routinely reports the status of volcano deformation to DPC but also acts during emergency crises with a higher temporal frequency.

Finally, thanks to the availability of an airborne platform, which is equipped with an X-band and L-band SAR sensor, IREA has implemented a pre-operative infrastructure referred to as the Multiband Interferometric and Polarimetric SAR (MIPS) system that, in conjunction with the already mentioned spaceborne systems, allows us to provide further information on the areas under study. Due to its flexibility, this system is particularly suitable during emergency scenarios and, for instance, allowed us to understand the elevation changes and the associated large mass wasting and accumulation that occurred during the 28 August 2019 paroxysm eruption at Stromboli volcano.

CONTACT

Francesco Casu

Phone +39 02-23699275

casu.f@irea.cnr.it

VOLCANOES

Imaging volcanoes' interior through proximal and remote observations

Filippo Accomando, Andrea Barone, Raffaele Castaldo, Vincenzo De Novellis, Francesco Mercogliano, Susi Pepe, Maddalena Perrini, Giuseppe Solaro, Pietro Tizzani, Andrea Vitale

Volcanic eruptions are geological phenomena controlled by endogenous factors at variable depths. Indeed, volcanoes are fed by plumbing systems, transporting magma from the Earth's mantle and crust towards the surface through a complex network of conduits. During this transfer, magmas undergo physical and chemical processes that affect the eruption feature, magnitude and duration.

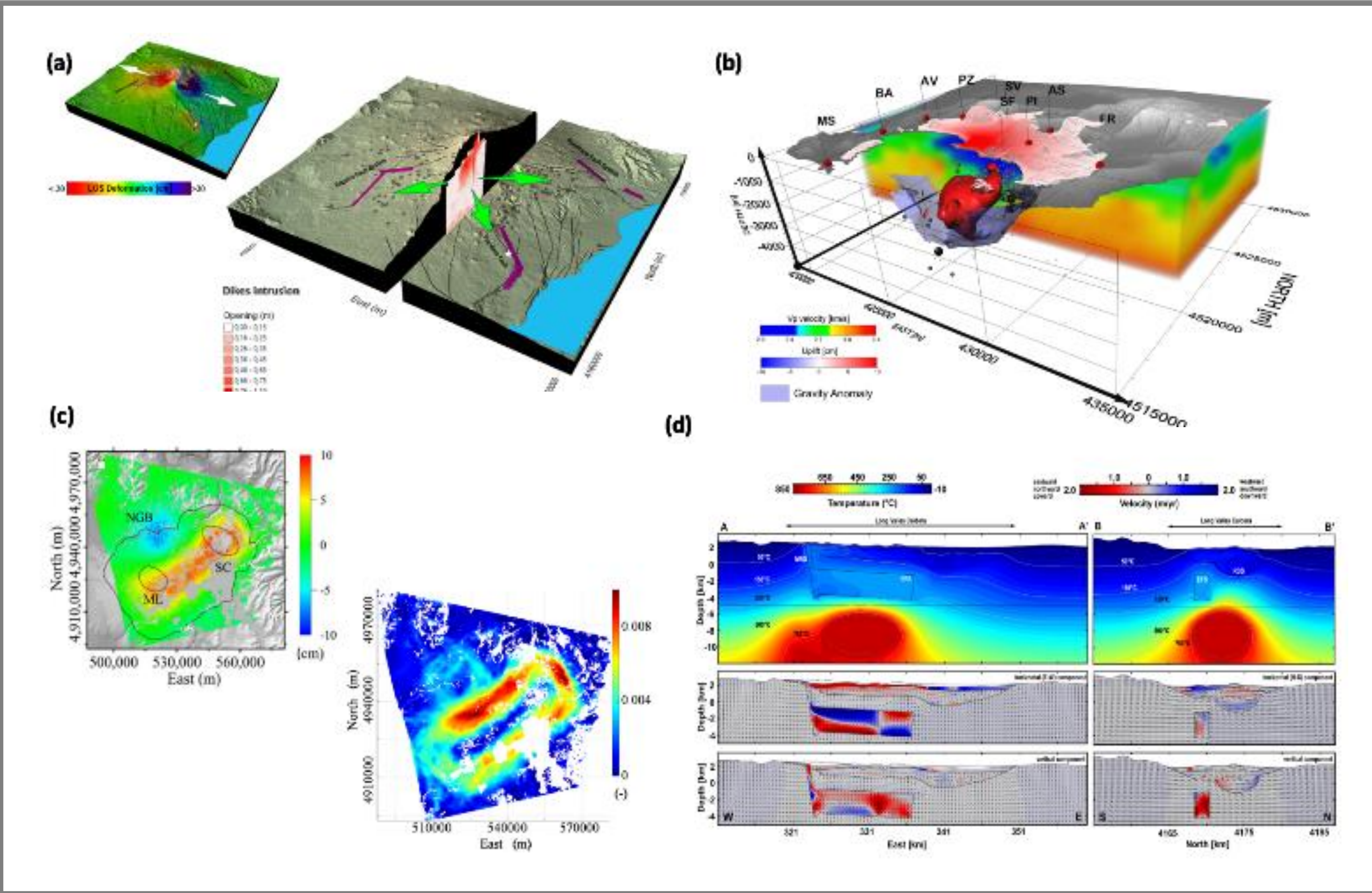
However, the temporal and spatial evolution of volcanic systems generally depends on embedding rock mechanical heterogeneities and pre-existing structural discontinuities. Consequently, the integration of different physical and chemical information becomes important to understand how the sub-volcanic engine works and perform a more reliable forecasting analysis.

In the last years, IREA research efforts have regarded the possibility of imaging the internal structure of active volcanoes, by jointly exploiting different data, such as ground deformation, temperature and seismic wave velocities combined with modelling approaches (analytical and finite element methods).

This integrated approach allows us to achieve important results in terms of the identification of the crustal regions with melt accumulation characterized by thermal anomalous fields, the definition of the physical processes governing the emplacement and evolution of magma reservoirs, and the enhancement of multiparametric monitoring of surveillance networks.

Another significant result concerns the understanding of the relationship between a seismic event that occurred at the base of an active volcano and the resumption of its eruptive activity, as in the case of the Etna volcano. More specifically, Etna volcano was characterized by a large eruptive activity on 24-27 December 2018 through the opening of lateral fissures on the eastern flank from which a lava flow expanded in the volcano-tectonic graben Valle del Bove. This event was accompanied by a surface deformation of more than 30 cm (see *panel a*). Moreover, the eruption was associated with a seismic swarm that culminated with a ML 4.8 earthquake occurred on 26 December 2018 along a strike-slip fault, which caused extensive damage to the surrounding villages. This result is very important because it allows us to investigate a possible feedback process of the Mount during the ascent and the emersion of the magmatic dike. However, although the most significant deformations occurred on 26 December, the other faults that border the unstable blocks of the volcano were also induced to move, accommodating the kinematics of the entire deforming sector toward a new tectonic balance.

Other examples of modelling and imaging the interior of volcanoes are concerned with the case of the Campi Flegrei caldera (see *panel b*), where the



Several examples of imaging of the interiors of volcanoes, achieved by the integrated approach based on modelling and multi-sensory observations

Panel C reproduced from Remote Sens. 2022, 14(21), 5328 - CC BY license (https://creativecommons.org/licenses/by/4.0/)
Panel D reproduced from Journal of Geophysical Research: Solid Earth, 126(2), e2020JB020331, (https://doi.org/10.1029/2020JB020331)

four-dimensional (space and time) internal structure was investigated by exploiting seismic tomography, gravimetric, three-dimensional geodetic and DInSAR data in an integrated approach.

Some advanced technologies have allowed us to study and model extensive volcanic complexes, such as the Yellowstone Caldera (USA). *Panel c* shows the cumulative vertical deformation map in the 2005–2007 time interval coming from ENVISAT DInSAR measurements, which is consistent with the Total Horizontal Derivative (THD) map computed on the same time interval and defines the volcanic source boundaries.

A final example comes from the use of temperature data to study the characteristics of magma at a certain depth, as in the case of the Long Valley caldera (USA). *Panel d* shows a conductive/convective thermal model computed via the Finite Element model. In particular, the mid-crustal temperature distribution and upper-crustal fluid velocity field (horizontal and vertical components), along two profiles North/North-South and East-East/West-West that cross the caldera region, and the normalized fluid velocity vectors (black arrows) are displayed.

CONTACT

Pietro Tizzani

Phone +39 081-7620635

tizzani.p@irea.cnr.it

LANDSLIDES

SAR Tomography for hydrogeological risk monitoring

Simona Verde, Diego Reale, Antonio Pauciullo, Eugenio Sansosti, Fabiana Calò, Pasquale Imperatore, Gianfranco Fornaro

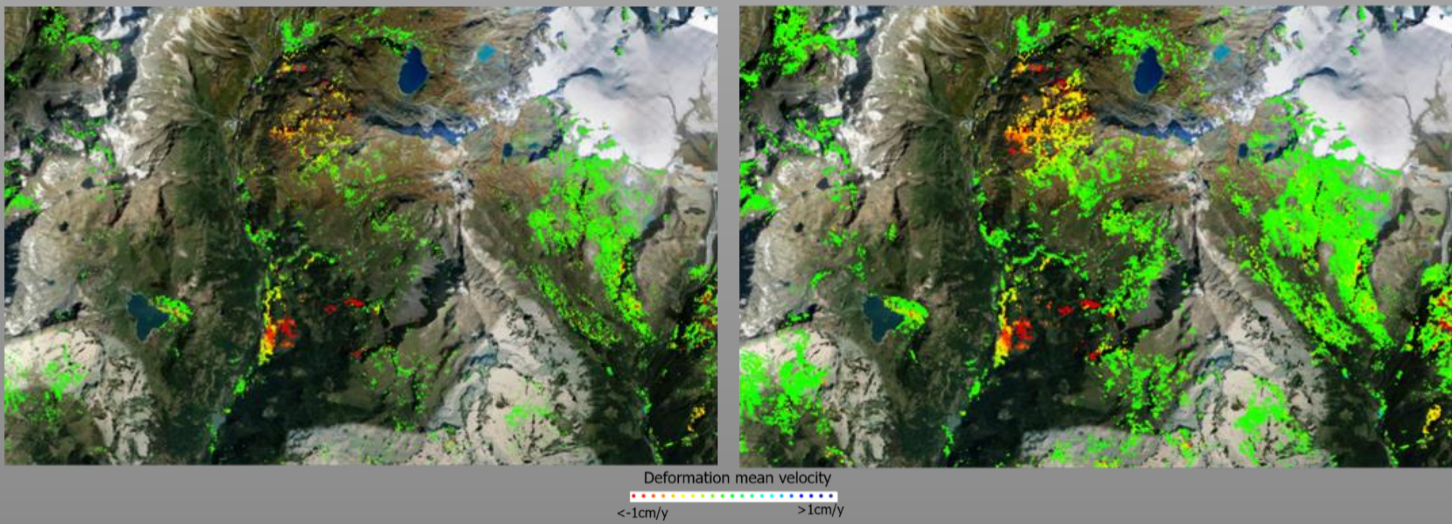
Landslide risk represents a major cause of injuries, property damage, socio-economic disruption and environmental degradation, also involving cultural heritage assets and critical infrastructures. Hydrogeological instability is a topic of particular relevance for the Italian territory: the 2021 Report on Landslides and Floods in Italy of the Italian Institute for Environmental Protection and Research (ISPRA) highlights that this geohazard involves 18,4% (55.609 km2) of the national territory and 1,3 millions of inhabitants. Therefore, mapping the rate of accumulation of such destructive geohazards and understanding their mechanics is of paramount importance to mitigate the resulting impacts and support risk prevention and mitigation.

In this regard, non-invasive spaceborne Earth Observation techniques, especially microwave remote sensing, have revolutionized the capability to measure ground surface displacements globally and synoptically. In particular, Differential Interferometric Synthetic Aperture Radar (DInSAR) has been widely exploited to investigate hydrogeological hazards and detect potential landslides on wide regions of the Earth's surface. Nowadays, it represents a consolidated tool in the field of geotechnical engineering for the analysis of slow-moving landslides.

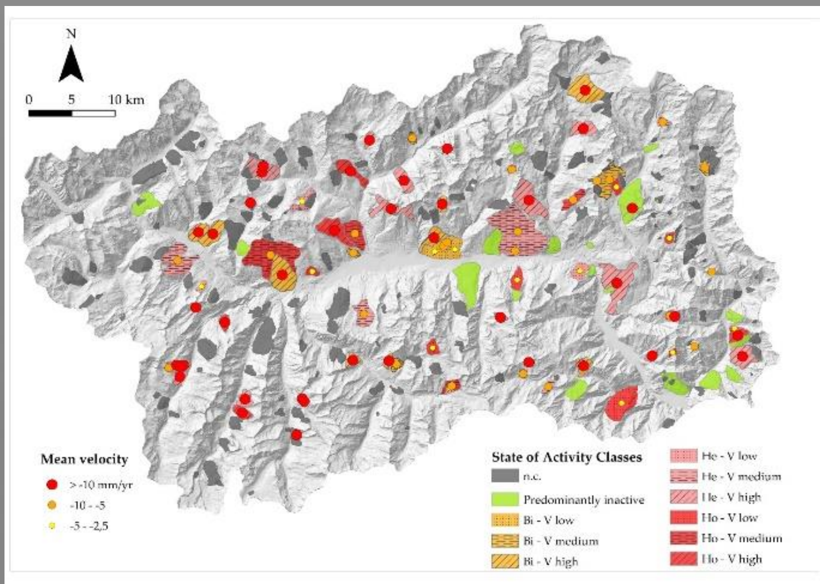
As the progress of the spaceborne SAR technology goes further, IREA researchers have developed innovative SAR data processing approaches based on the exploitation of the SAR data stack acquired in repeated passes of the satellite. In particular, SAR Tomography is a technique for the analysis of multipass SAR data, first demonstrated by the IREA research group. It implements a “radar scanner” from space, which allows us to “inspect” very accurately the observed scene.

As shown in Figure 1, the result of the tomographic processing is a mean deformation velocity map of the detected measurement points, and for each point the displacement time series is available. The example shows the mean deformation velocity map achieved by SAR Tomography processing of Sentinel-1 data acquired in the Aosta Valley Region (Western Italian Alps).

The availability of very high-resolution SAR data promoted the tomographic monitoring capabilities, leading to a major step toward risk analysis at a single facility level. The high-resolution tomographic analysis allows us to zoom in on the specific sites of interest, thus providing deformation information of wide areas of the Earth's surface at the highest available spatial resolution. This aspect can specifically concur with the geometric and kinematic characterization of slow-moving landslides, as well as in the vulnerability analysis of facilities under risk. In fact, the measurement points derived from SAR Tomography processing, for each of which deformation times series can be derived with cm/mm accuracy, can be combined with conventional ground-based monitoring data, geotechnical criteria, and



Mean deformation velocity map achieved by SAR Tomography processing of Sentinel-1 data acquired on Aosta Valley Region (Western Italian Alps) (on the left) and multi-resolution SAR Tomography processing, overlaid on an optical image by Google Earth (on the right).



State of activity of DsGSD at regional scale in Aosta Valley Region (Western Italian Alps)

structural damage estimation methods.

It is worth stressing that landslide analysis is a rather complex problem, including different kinds of phenomena, both in terms of kinematics and coverage characteristics. Hence, the research challenge moves towards the improvement of SAR processing techniques with respect to the problem of enhancing the spatial coverage of deformation measurements in different environmental contexts. Recently, IREA researchers have proposed a tomographic analysis exploiting a multi-resolution approach that represents a further advancement for mapping and monitoring areas prone to landslide risk. It allows increasing the spatial density of measurement points, even in areas typically characterized by a lack of information (as f.i rural and/or sparsely vegetated areas), preserving at the same time the high-quality information of coherent point-wise scatterers, which are typically associated with built structures and infrastructures.

Figure 1 shows a comparison between the result achieved by the classical SAR Tomography (on the left) and the multi-resolution SAR Tomography approach (on the right). The improvement in terms of an increased density of measurement points is clearly appreciable.

Moreover, by exploiting post-processing procedures on deformations maps, it is possible to classify the state of activity and spatial distribution of deep-seated gravitational slope deformation (DsGSD) at a regional scale. An example is given in figure 2, which is relevant to the classification of the state of activity of DsGSD at a regional scale catalogued (listed) in the regional landslide inventory of the Aosta Valley Region (Western Italian Alps), by exploiting SAR Tomography processing of Sentinel-1 data.

CONTACT

Simona Verde
Phone +39 081-7620630
verde.s@irea.cnr.it

New frontiers for monitoring, analysis and modelling of landslides phenomena

Filippo Accomando, Andrea Barone, Raffaele Castaldo, Vincenzo De Novellis, Francesco Mercogliano, Susi Pepe, Maddalena Perrini, Giuseppe Solaro, Pietro Tizzani, Andrea Vitale

Landslides represent extremely widespread phenomena that cause significant impacts on the different exposed elements, such as the population, the inhabited centres and the critical infrastructures. With an inventory reporting over 620,000 events, Italy is the country with the highest frequency of landslides occurrence in Europe.

For such kind of scenario, multi-platform monitoring systems are essential to better understand and monitor the physical processes associated with the landslides' contributing factors and evaluate the related deformation trends. This study is crucial for supporting an appropriate risk mitigation analysis, also proposing and testing procedures of early warning to protect human lives. In this context, the development of new frontiers and technologies is a fundamental topic for monitoring these natural phenomena and a more reliable assessment of the risk factors.

In recent decades, IREA researchers have aimed at identifying new frontiers of multi-parametric monitoring systems and multiphysics modelling of slow and fast landslides.

The research activities have shown the potential of satellite remote sensing techniques in monitoring and detecting slow landslides and the innovative System (UAS) platforms for very high-resolution contribution provided by the Unmanned Aircraft monitoring of the slope instability (from the mesoscale to the local scale) through the electromagnetic sensing of the areas affected by significant hydrogeological risk.

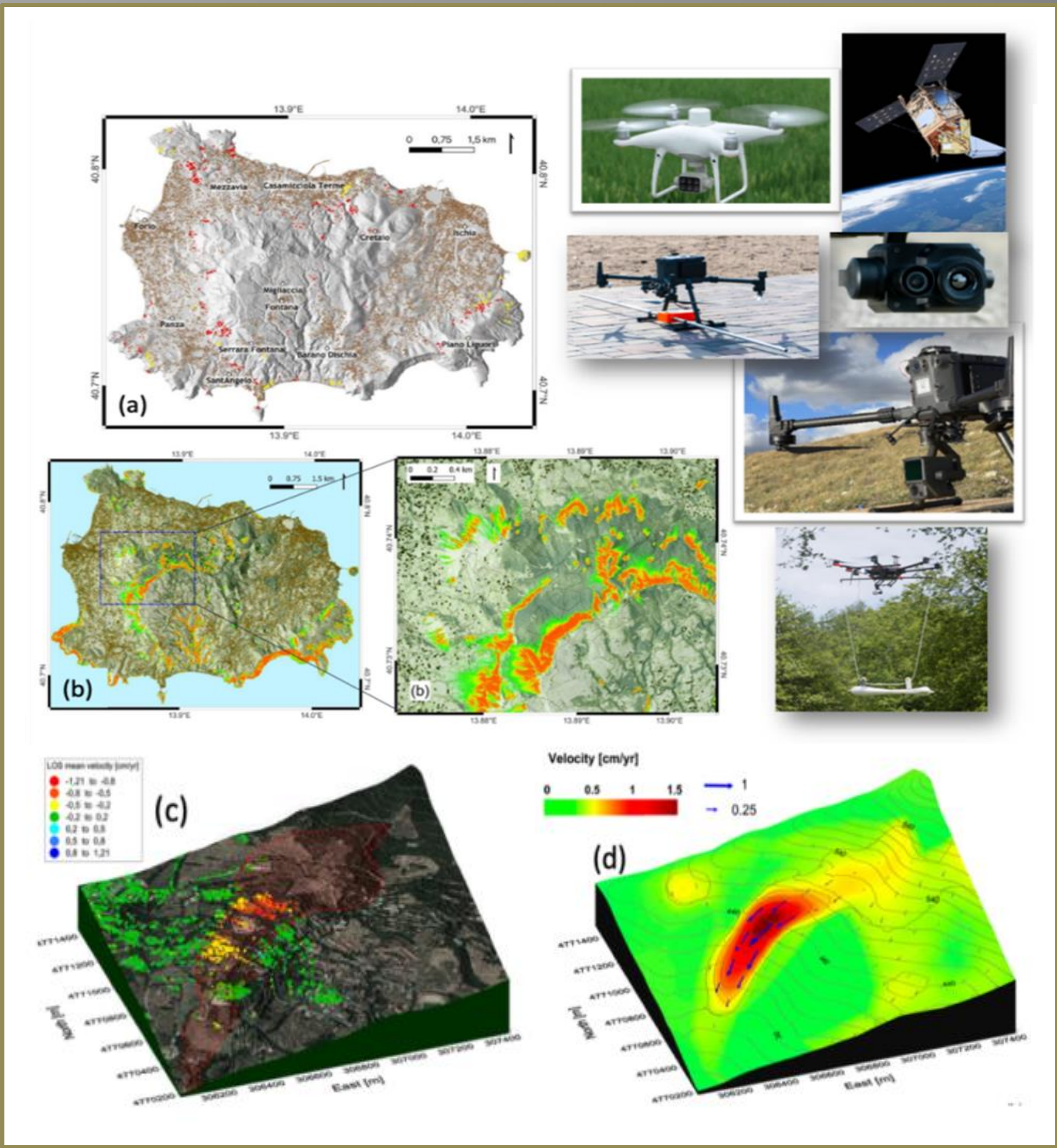
In the figure several relevant results of the above-mentioned research activities are shown.

(a) Map of potential rockfall impacts of simulated trajectories on infrastructures of Ischia Island (a);

(b) Ischia Island rockfall trajectories simulated with STONE algorithm and (Inset - b) the zoomed region around Mt. Epomeo volcano-tectonic horst;

(c) DInSAR CSK mean deformation velocity map of Ivancich slow landslides event (Assisi-Italy) superimposed on the 3D view of satellite optical image superimposed to the DEM of the area;

(d) 3D view of optimized FE multiphysics model velocity map simulating the field reported in the figure.



CONTACT

Raffaele Castaldo

Phone +39 081-7620636

castaldo.r@irea.cnr.it

LANDSLIDES

Advanced trend analysis of interferometric displacement time series for instability monitoring

Fabio Bovenga, Alberto Refice, Antonella Belmonte, Ilenia Argentiero

Multi-temporal SAR interferometry (MTInSAR) allows the analysis of wide areas, identifying ground displacements, and studying the phenomenon evolution on long-time scales by providing both mean displacement maps and displacement time series over coherent objects on the Earth's surface. This technique has also been proven to be very useful for detecting and monitoring instabilities affecting both terrain slopes and man-made objects.

Warning signals related to landslides or the pre-failure of buildings and artificial infrastructures are typically characterized by high rates and non-linear kinematics, so reliable monitoring and early warning require a detailed analysis of the displacement time series searching for specific trends.

However, this detailed analysis is often hindered by the large number of coherent targets (up to millions) required to be inspected by expert users in order to recognize different signal components and discriminate possible artefacts affecting the MTInSAR products.

Our research is aimed at developing methods able to fully exploit the content of MTInSAR products, by automatically identifying relevant changes in displacement time series and classifying the targets on the ground according to their kinematic regime.

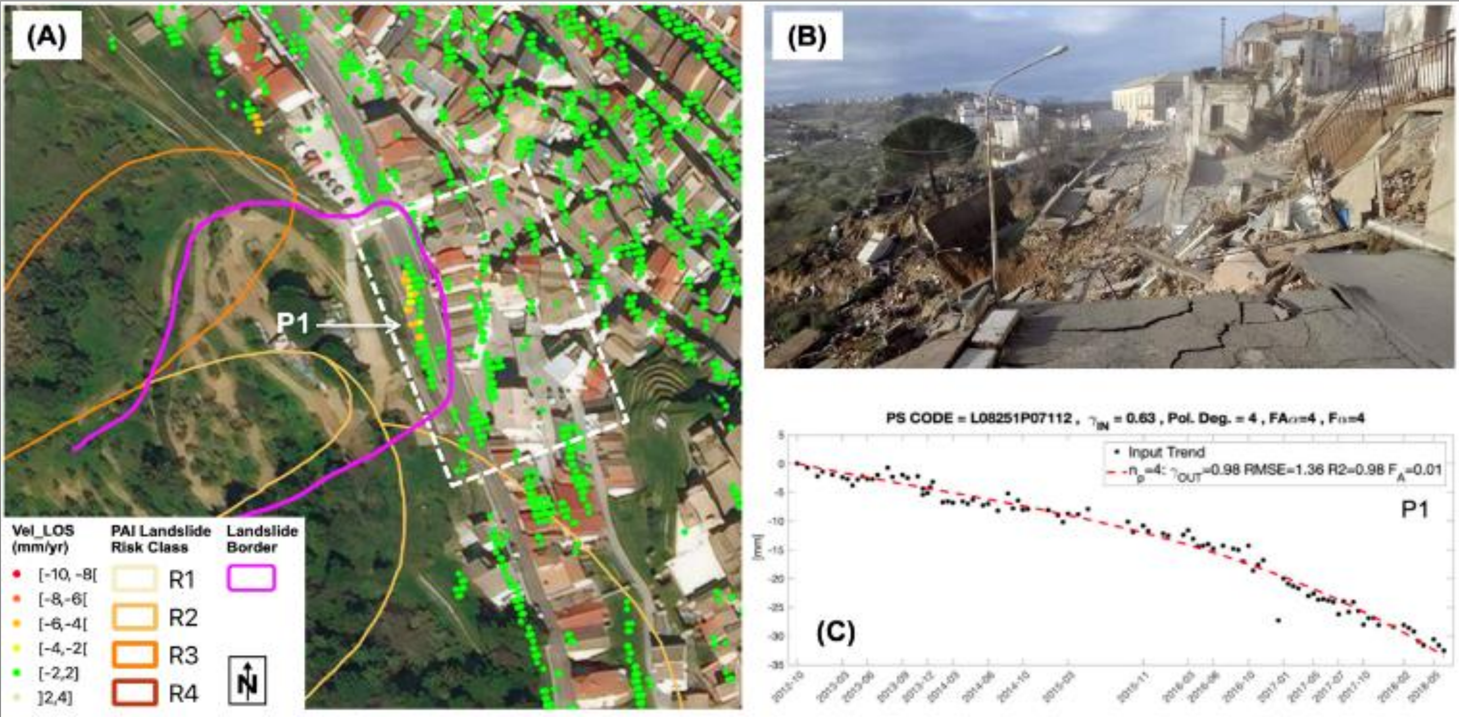
IREA researchers proposed a new set of rules based on the statistical characterization of displacement time series, which allows us to select a function that approximates the MTInSAR time series. This method was applied to model warning signals.

Moreover, in order to measure the degree of regularity of a given time series, an innovative method was proposed, which compares signal segments of different time lengths. This model allows us to highlight time series showing interesting/unexpected trends, including strong non-linearity, jumps related to processing errors, and fluctuations resulting from a transitory noisy behaviour of the targets.

Both algorithms were tested under simulated scenarios to evaluate their performance, and after on displacement time series derived by processing both Sentinel-1 and COSMO-SkyMed data.

The proposed procedures allow us to focus on the geophysical or geotechnical analysis of the MTInSAR products on a smaller set of coherent targets, which are selected according to the displacement kinematic model of interest.

An interesting example is provided by the case study of Pomarico, a hilly village located in the Southern Italian Apennines, where a landslide occurred in the recent past causing damage to houses and infrastructures. The proposed procedures were able to select targets (namely P1 in the Figure) evidencing non-linear displacement trends, which



(A) Line of sight displacement rate map over the Pomarico landslide derivered by MTInSAR processing of COSMO-SkyMed data; (B) Picture of the urban area affected by the landslide and bordered by the white rectangle in (A); (C) Displacement time series corresponding to target (labelled P1 in (A)) selected by the proposed procedures.

represent pre-failure signals related to building deformations preceding the Pomarico landslide and the collapse. This allowed us to understand the phenomenon's evolution, highlighting a change in velocities that occurred two years before the collapse. This velocity variation probably influenced the landslide dynamics, which led to the collapse of an area considered to be at a medium-risk level by consulting the regional landslide risk map.

On the same subject, further research activities are ongoing, which focus on the use of machine learning techniques.

CONTACT

Fabio Bovenga

Phone +39 080-5929425

bovenga.f@irea.cnr.it

SEA

Radar systems for sea state monitoring

Giovanni Ludeno, Francesco Soldovieri, Ilaria Catapano, Gianluca Gennarelli, Giuseppe Esposito

Sea plays a fundamental role in the social and economic development of countries and in the present and future issues related to climate change. This has led to growing attention by the scientific community towards the sea state and its behaviour. Moreover, climate change is exacerbating many risk factors such as coastal erosion and pollution, and increasing the frequency and magnitude of damaging events (e.g. the ongoing rise in sea level, increased number of storms and flooding, etc.).

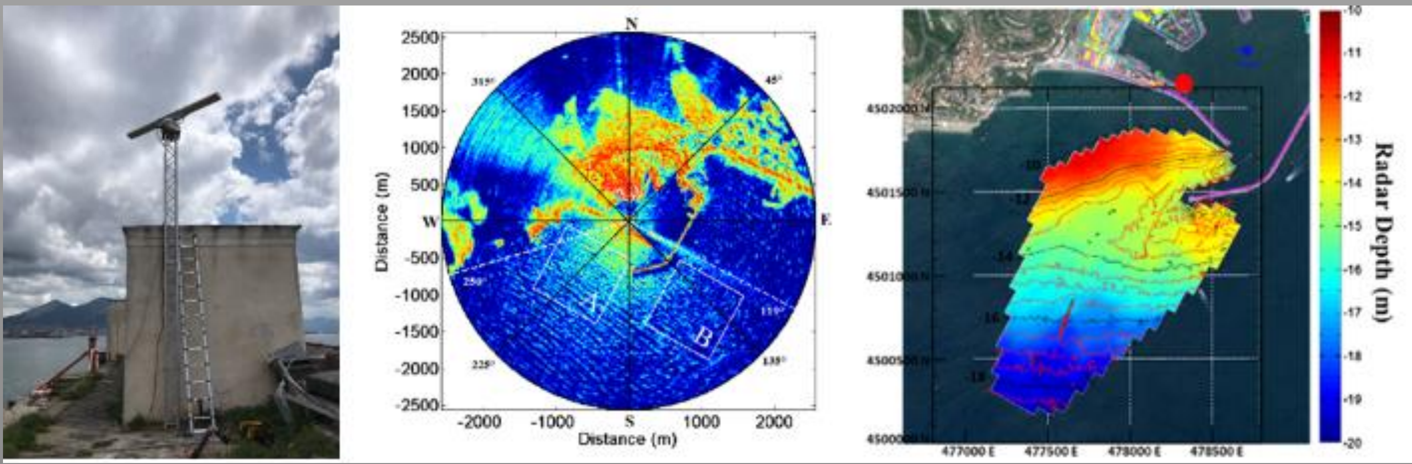
In the last decades, several monitoring systems have been developed, which help understand the sea state both in the coastal and offshore areas. Retrieving information about the characteristic sea state parameters is one of the key points for studying and analysing the damaging events due to climate change. In this frame, marine radar systems have attracted considerable attention for sea state monitoring since they permit a non-invasive and remote observation of the sea surface in severe weather and sea wave conditions.

Indeed, they permit a non-invasive and remote observation, in space and time, of the sea state in severe weather and sea wave conditions, thus providing a valid alternative to classical in-situ sensors (e.g. wave rider buoy). However, non-trivial radar data processing is needed for measuring sea wave spectra and retrieving sea state information.

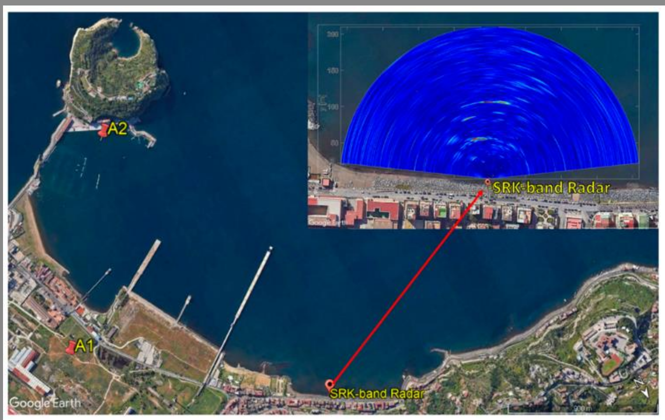
In this context, IREA research activities focus on the development of ad-hoc methodologies for the estimation of sea state parameters, such as wavelength, period, direction of the dominant wave, and significant wave height as well as for the reconstruction of sea surface current and seabed depth maps with a high spatial resolution.

X-band Marine radar (MR) and Short-Range K-band (SRK-band) radar systems are available at IREA. These systems allow observing the sea surface with different spatial and temporal resolutions. Specifically, MR allows observations in a range of a few kilometres from the platform and provides a spatial resolution of a few meters, while the SRK-band has a smaller range coverage (hundred meters) than MR, and provides a range resolution lower than one meter. These peculiar features make the two radar systems complementary in the context of sea state monitoring since they observe the phenomena at different spatial scales and resolutions.

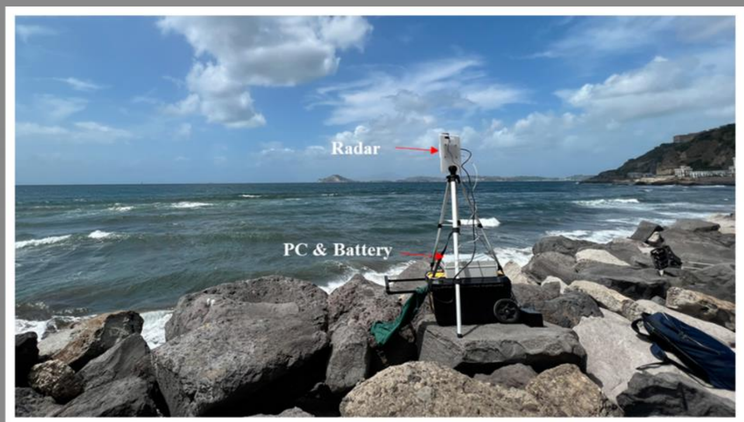
To date, MR is a well-assessed tool both in the context of maritime situational awareness (i.e. detection and tracking of targets in the surroundings of a ship during navigation) and sea state monitoring. On the other hand, the usage of SRK-band radar for these specific applications is at the state of the art. Therefore, IREA research is focused on the exploitation of the peculiar characteristics of SRK-band radar (e.g. small size, lightweight, low emitted power, and small range coverage) to support the navigation of autonomous surface vehicles and analyse sea waves very close to the coast and in semi-closed areas (e.g. bay, harbour, lake, etc.).



Marine (X-band) radar in action; Radar image of the sea; Map of the seabed of Salerno (Italy) port derived by marine radar measurements.



Short-range K-band radar image of the sea



Short-Range K-band radar installation

CONTACT

Giovanni Ludeno

Phone +39 081-7620653

ludeno.g@irea.cnr.it

FLOODS

Monitoring of flood events with high resolution through SAR and optical data

Alberto Refice, Annarita D'Addabbo, Antonella Belmonte, Fabio Bovenga, Francesco P. Lovergine, Giacomo Caporusso

Floods are among the costliest hazards in Europe and worldwide, with intensities and impacts on infrastructures and agriculture, proven to be increasing due to climate change.

Research is currently devoted to both forecasting events and monitoring floodwater distributions over large areas and long timescales. The latter benefits from the large and increasing availability of remotely sensed imagery acquired with high resolution in both the spatial and temporal domains.

In particular, the availability of long time series of images acquired by both Synthetic Aperture Radar (SAR) and optical sensors allows us to determine the spatial distribution of inundated areas at each acquisition, over large portions of territory and with high precision.

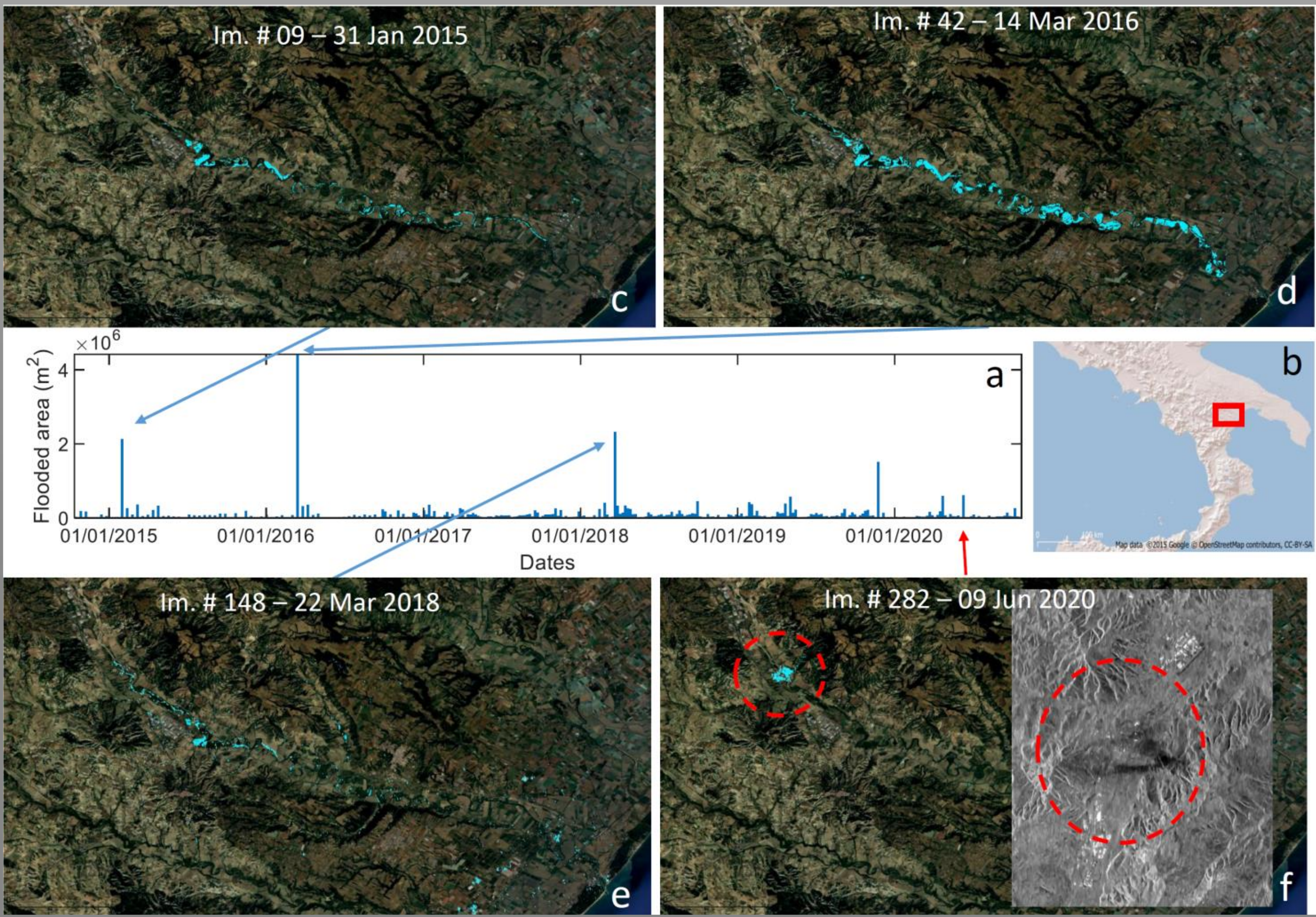
At IREA, research activities are ongoing to improve the performance of algorithms for mapping flood events from multi-temporal SAR image stacks. We exploit the increased revisit time frequency of recent sensors, such as the European Sentinel-1 constellation, to detect short-lived events lasting for a single or a few consecutive acquisitions.

In particular, we use Gaussian Process (GP) regression to account for slow backscatter changes on land areas, based on the assumption that floods are short-lived events with respect to land cover changes.

GP regression has several advantages over the usually exploited parametric regression, which overcome their higher computational cost. The Bayesian framework also allows us to consider ancillary information such as topography and satellite acquisition geometry, which can be cast into prior probability distributions, which taper to zero for locations unlikely to be flooded.

We tested the approach over the coastal area of the Basilicata region, in Southern Italy, which is affected by recurrent flood phenomena, increasing in intensity in the last years. We processed a stack of 303 Sentinel-1 images acquired in ascending geometry, covering a time interval from 2015 to 2021. We exploited the topography - a 5-m digital terrain model (DTM) provided by the Regione Basilicata, processed to obtain the Height Above the Nearest Drainage (HAND), as well as slopes and a map of SAR layover and shadow areas.

The figure shows samples of the total flooded area, computed by considering the pixels with a posterior probability of being flooded greater than 0.5 over the extent shown in the maps. The maps highlight some snapshots in time corresponding to peaks in the flooded area trend. Most of the highest peaks correspond to known events, such as the one on March 14, 2016. The peak labelled with the red arrow corresponds to a false alarm due to the



Time series plot of the total flooded area over the Basilicata test site (corresponding to the red rectangle in the location map in b). (c-f) Sample flood maps corresponding to peaks in the plot are shown above and to the right. The last map corresponds to the presence of a large cloud that obscures the SAR signal.

presence of a large cloud causing an extended area with low backscatter.

The methodology is undergoing validation through comparison with independent data (e.g. High Resolution or Very High Resolution optical imagery or maps coming from the Copernicus EMS service).

Finally, it is worth stressing that each pixel or small terrain patch is treated virtually independently within our processing chain, so parallel computing solutions can easily be adopted.

CONTACT

Alberto Refice

Phone +39 080-5929432

refice.a@irea.cnr.it

Change Detection and Artificial Intelligence techniques for land surface changes mapping and monitoring

Antonio Pepe, Fabiana Calò, Pietro Mastro, Francesco Falabella

Remote sensing methodologies play a key role in the prevention and mitigation of natural and man-made hazards, contributing to decision-making processes and effective disaster risk management plans.

One of the most relevant techniques in this context is change detection, a process that analyzes two or more remotely sensed images captured over the same geographical area at different times to identify significant land changes that have occurred in the observed period.

Optical space-borne sensors have historically extensively been used for change detection in a variety of applications, i.e., crop growth monitoring, analysis of vegetation and forest changes, urban sprawl detection, and snow cover monitoring.

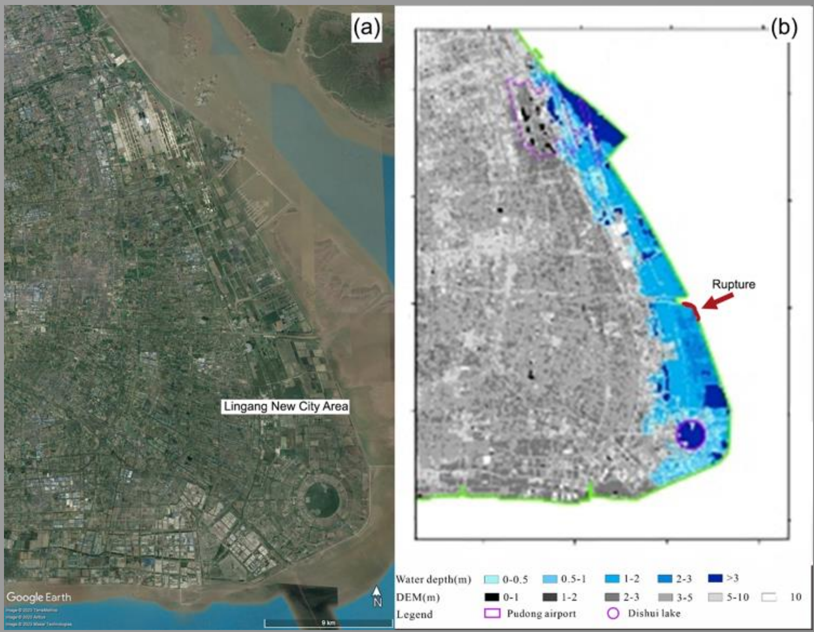
Unlike optical sensors, microwave images acquired by Synthetic Aperture Radar (SAR) sensors have less been exploited in this field. Despite the complexity, SAR images are attractive in change detection analyses from the operational viewpoint since SAR sensors are active instruments operating in every weather and sunlight conditions. This means that SAR-based remote sensing allows the systematic monitoring of geographical areas, overcoming the limitations of optical image use due to cloud coverage.

In this context, some activities are ongoing for the analysis of the combined effects of sea level rise, subsidence, coastline changes, and the impact of extreme events in coastal areas. These studies are beneficial for land and water management and lead to cascading benefits in other sectors in these vulnerable regions where the risk of flooding may seriously impact the population.

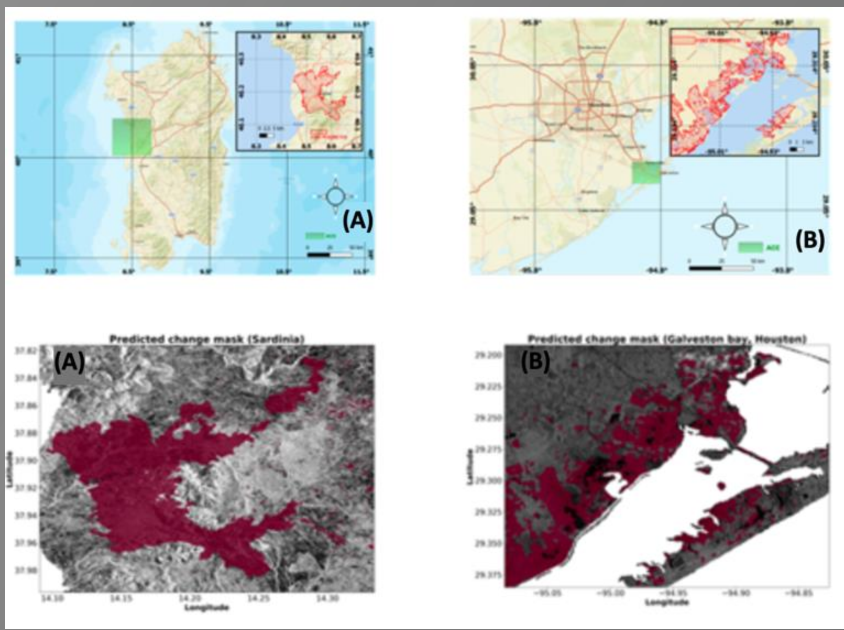
As examples of application, we show in Figure 1 the results of the analysis of terrain elevation changes and associated risk of flooding in selected Chinese coastal areas between 2000 and 2015. In particular, the hydrodynamic model LISFLOOD-FP, which is a two-dimensional hydrodynamic model specifically designed to simulate floodplain inundation over complex topography, was employed to map coastal inundation areas of Shanghai by evaluating the effect of potential flooding due to the failure of every segment of the seawall line.

Over the recent decades, a new emerging research line relying on machine learning approaches has also gained a very central role in change detection, thanks to its ability to outperform traditional methods. The adoption of these approaches is fostered by the availability of new advanced satellite sensor constellations capable of collecting a wide range of data, and providing information with unprecedented temporal/spatial accuracy and resolution.

Artificial Intelligence-assisted SAR approaches have been applied for detecting and mapping changes in flooded and burned regions, considering several test site areas in Italy and abroad (Figure 2). These



Risk of inundation and analysis of expected impact in the Shanghai coastal region. (a) Google Earth optical image of the reclaimed Lingang New City area of the Shanghai megalopolis. (b) Simulated inundated areas in the case where a specific segment (red arrow) of the seawall line could fail or be overtopped by waves in vey extreme weather conditions.



Maps of predicted changed areas in Sardinia (a), and in the city of Houston (b) due to effects of wildfires occurred in Italy during the 2021 summer season and a serious inundation that hit the city of Houston on 25 August 2017.

methods also consider ancillary information, such as the interferometric coherence among pairs of SAR images.

A series of synthetic change detection indices are used to track changes on the ground due to fires and inundations. Three study areas, i.e., Sardinia, Sicily and the city of Galvestone in the U.S., were analyzed. Three sets of SAR images collected by the European Copernicus Sentinel-1A/B sensors, were exploited to perform the presented analyses. After SAR data pre-processing, a random forest classifier based on the used change detection indexes has been trained and the spatial distribution of changed areas has been retrieved.

CONTACT

Fabiana Calò
Phone +39 081-7620633
calo.f@irea.cnr.it

BUILDINGS AND INFRASTRUCTURES

Deformation analysis over the built environment

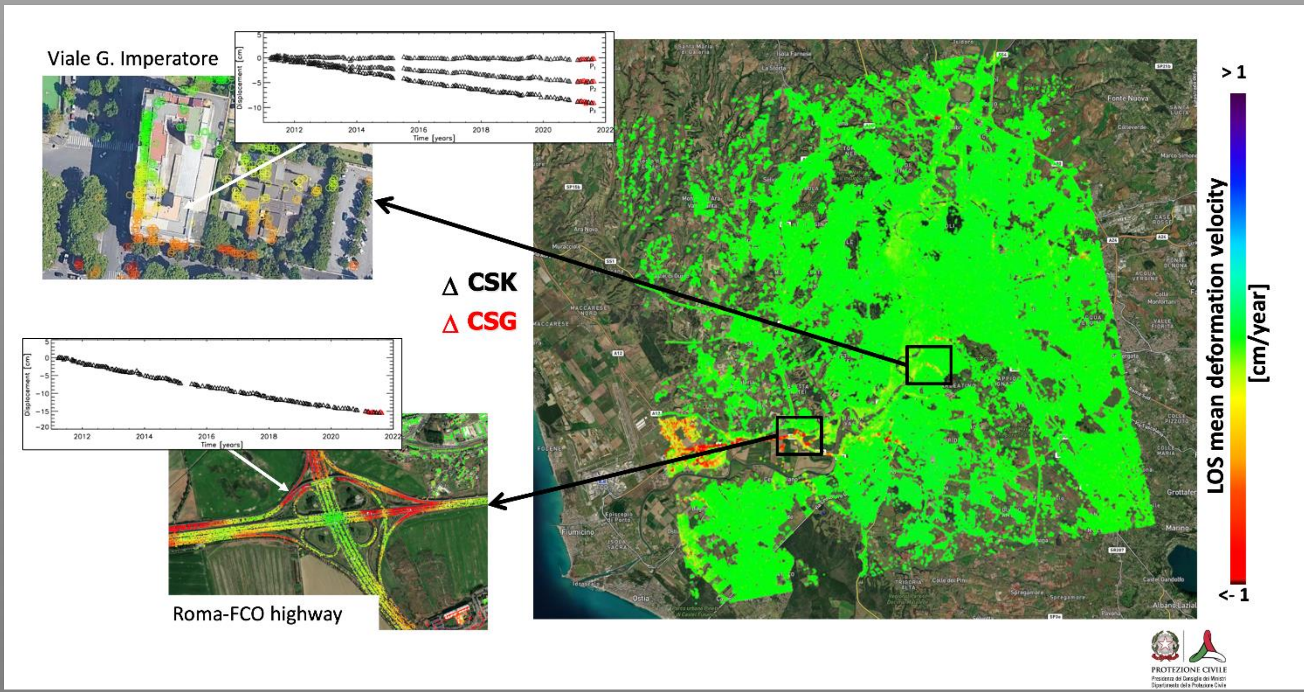
Manuela Bonano, Sabatino Buonanno, Federica Casamento, Francesco Casu, Federica Cotugno, Claudio De Luca, Adele Fusco, Michele Manunta, Giovanni Onorato, Yenni Lorena Belen Roa, Pasquale Striano, Muhammad Yasir, Giovanni Zeni, Ivana Zinno, Riccardo Lanari

The need to assess and preserve the health conditions of structural and infrastructural heritage is a worthy research topic dictated by the high vulnerability of the built-up environment and the relatively large number of existing infrastructures that have almost reached their service life. The detection and monitoring of localized deformation patterns induced by natural and/or anthropic causes is a fundamental point to prevent and mitigate the associated risks, which can also be tackled through innovative, non-invasive structural monitoring techniques.

In this context, the use of satellite remote sensing technologies based on Synthetic Aperture Radar (SAR) images looks very promising when dealing with large areas and long observation periods. Indeed, the widespread accessibility of large archives of SAR images acquired by advanced satellite systems has fostered the development of multi-temporal Differential Interferometric SAR (DInSAR) techniques for high spatial resolution applications. Such methodologies can detect localized displacements in different hazard scenarios related to both natural and built environments by generating spatially and temporally dense deformation time series and corresponding mean velocity maps over vast areas, with millimetric accuracy and relatively limited costs of the performed analyses. This may provide value-added information to be profitably used for the monitoring, assessment and surveillance of the health conditions of cities, critical infrastructures and archaeological sites.

Since 2001, IREA has been at the cutting edge of the development and implementation of advanced multi-temporal DInSAR techniques able to exploit long SAR data sequences acquired by various Earth Observation satellite systems. In particular, the advanced DInSAR technique referred to as full resolution parallel Small BAseline Subset (FR P-SBAS) approach can perform long-term advanced DInSAR analyses related to extended urban areas by generating deformation time series at the full spatial resolution of the exploited SAR sensors. Its effectiveness consists of the capability to perform long-term multi-temporal DInSAR analyses at different spatial resolutions (for regional and local scale investigations) that are appropriate to identify and monitor localized deformation phenomena, such as those affecting critical infrastructures and single buildings.

With this regard, IREA has recently performed extensive full-resolution P-SBAS processing through several case studies relevant to wide urban areas. They confirm how the use of these measurements is becoming increasingly important in the field of localized deformation monitoring and structural health assessment. In particular, by exploiting large sequences of multi-temporal X-band CSK/CSG SAR data archives collected over the main cities of the Italian territory (e.g., Roma, Napoli, Milano, Venezia, Catania), it is possible to monitor through the



Full resolution CSK/CSG P-SBAS based results relevant to the urban area of Roma and surroundings (Central Italy). (Right) LOS mean deformation velocity map (ascending orbits) relevant to the 2011-2021 time span. (Left) Zoom-in views of the deformation map and time series of selected coherent pixels relevant to: (top) a building in the city centre affected by differential displacements along the North-South facade; (bottom) the Roma-Fiumicino Airport highway

full-resolution P-SBAS approach the localized deformation patterns related to extended urban areas and, at the same time, to detect and investigate potentially critical conditions of transport infrastructures and single buildings (see Figure).

We further remark that, as a Centre of Competence of the Italian Civil Protection Department (DPC) in the field of ground deformation monitoring through advanced DInSAR techniques, the IREA team has recently contributed to drawing up the first document of “Guidelines for the use of satellite interferometric data for the interpretation and assessment of the structural behavior of buildings and infrastructures”, in synergy with the Network of the University Laboratories of Seismic Engineering (ReLUIS) consortium.

Nowadays, the new frontier of the exploitation of the full-resolution P-SBAS technique concerns its effectiveness within an operational scenario, to investigate localized deformation affecting infrastructures and single buildings at a national scale level. In such a framework, we have recently implemented some further advancements in the full-resolution P-SBAS processing chain, aimed at effectively monitoring the deformation signals associated with the built-up heritage at a national scale. To this aim, we exploit both advanced DInSAR processing techniques based on up-to-date parallel strategies and modern HPC e-infrastructures, mostly based on Graphical Processing Unit (GPU) that can guarantee high efficiency and scalability performance, to efficiently process large full-resolution interferometric data stacks in short time frames (less than 12 hours for the overall CSK/CSG frame) and possibly extract value-added information from the P-SBAS products.

Finally, we are focusing on the forthcoming Italian IRIDE constellation, developed through the National Recovery and Resilience Plan (PNRR) of the Next Generation EU program, which will include an X-band SAR component that will further extend the advanced DInSAR methods capabilities to assess the health conditions of the Italian built-up environment.

CONTACT

Manuela Bonano

Phone +39 081-7620633

bonano.m@irea.cnr.it

BUILDINGS AND INFRASTRUCTURES

Ground Penetrating Radar for in situ diagnostics and monitoring of built environment

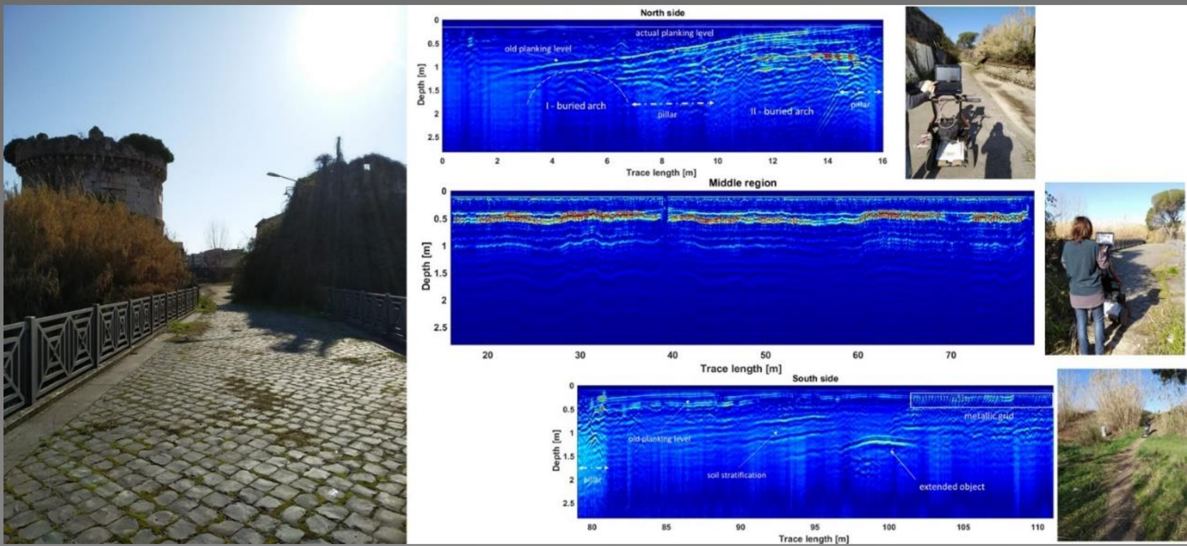
Ilaria Catapano, Giuseppe Esposito, Gianluca Gennarelli, Carlo Noviello, Francesco Soldovieri, Mehdi Masoodi, Giovanni Ludeno

Ground Penetrating Radar (GPR) is an assessed and widespread technology capable of providing high-resolution images of the interior features of the investigated scenarios (i.e., underground, man-made structures and so on) with a spatial resolution that varies from centimetres to a few meters depending on the application's needs. In the frame of infrastructure and building diagnostic and monitoring, GPR is becoming a more and more exploited technology to gather information on the constructive and reinforced components as well as to detect cracks and anomalies due to ageing. This increasing use implies, on the one hand, the need to improve the readability of the GPR images and, on the other, the demand for innovative technological solutions devoted to improving the surveys' flexibility and reducing their costs and times.

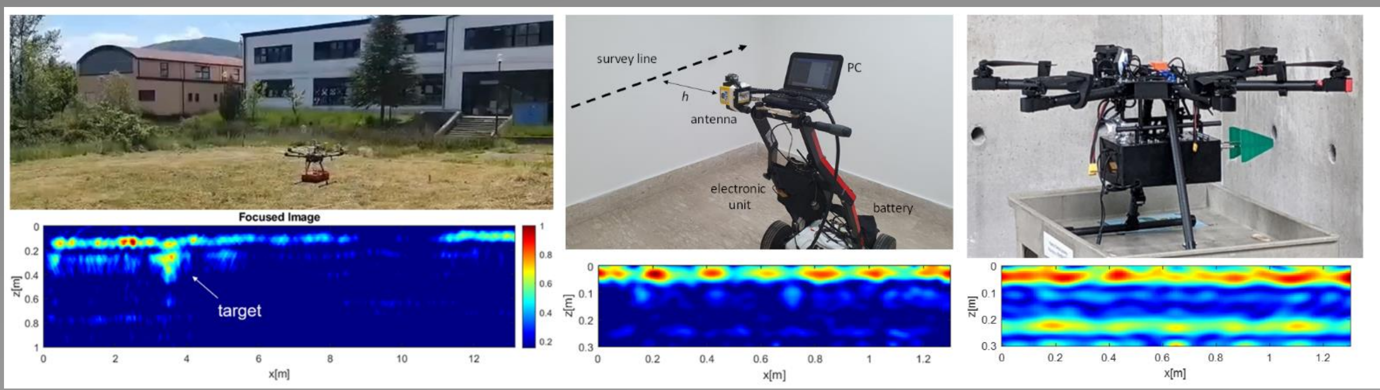
These two open challenges are the core of the research activities carried out at IREA.

Since 2001, research activities regarding the design, testing and on-field application of advanced GPR data processing strategies have been performed, and several contributions have been provided in this frame. Synthetically, the designed approaches, beyond exploiting standard filtering procedures, face the imaging as an inverse scattering problem, which is formulated by properly modelling the signal propagation. The main advantage of these approaches is their flexibility, i.e. their ability to manage different scenarios (e.g., subsurface or vertical structures like the facade of a building) and data collected by various measurement systems, such as standard single channel systems, allowing the collection of multi-monostatic data and new generation of multi-channel systems capable of gathering multiple input – multiple output (MIMO) data. Furthermore, the designed approaches are robust against uncertainties in the reference scenario and provide an accurate localization and a rough estimation of the geometrical features of the targets, which are sufficient information in many GPR applicative fields.

Over the years, these approaches have been optimized to move towards accurate three-dimensional reconstructions of the investigated scenarios and applied to image the inner of buildings and infrastructure components, like floors, walls and pillars. Among the others, three relevant examples are the evaluation of Ponte Lucano, the Roman masonry bridge in Tivoli (Roma), the reinforced concrete Musmeci bridge in Potenza and the Gravina bridge in Matera. Further valuable contributions regard the use of the designed GPR data processing approaches as a tool to generate images, which are exploited for monitoring the time evolution of cracks, as in the case of the Consoli Palace in Gubbio, and the wall humidity trend, as in the case of the Cripta of Santa Agnese in Agone, Roma.



GPR survey at the Roman masonry bridge Ponte Lucano, Tivoli (Roma)



UAV mounted GPR survey of subsoil and vertical structures

In the last years, the research activities have been extended to face the issues related to GPR systems mounted on unmanned aerial vehicles (UAVs). In this field, the research activities carried out at IREA are at the state of the art concerning the international context and account for both hardware and software aspects.

Specifically, devoted data processing approaches for UAV-based GPR have been developed and tested against synthetic and experimental data. Furthermore, technological challenges such as the synchronization between UAV position and radar acquisition, the compensation of drone motion deviations, and the need to manage large amounts of data while assuring reliable results in quasi-real time have been considered. The design of prototypes suitable to investigate vertical structures is the subject of ongoing activities.

Further pioneering activities regard the design of convolutional neural network-based procedures for automatic target recognition in MWT images.

CONTACT

Ilaria Catapano

Phone +39 081-7620645

catapano.i@irea.cnr.it

CULTURAL
HERITAGE

Microwave and Terahertz signals for cultural heritage management and protection

Ilaria Catapano, Francesco Soldovieri, Gianluca Gennarelli, Giovanni Ludeno, Giuseppe Esposito

At the European level, the widespread presence of valuable and accessible cultural assets makes the need for sustainable management and protection of such a heritage, crucial to mitigate its vulnerability to environmental crisis events (earthquakes, landslides, etc.) and extreme climatic events. This necessity is amplified by the socio-economic impact that the cultural assets have for Europe and, in particular, for the Mediterranean area, where cultural tourism contributes significantly to the territory's progress.

Authorities who oversee cultural heritage sites are increasingly aware that the management and protection of their sites is possible only with a holistic approach that encompasses engineering, physics, and social sciences and requires the design and implementation of integrated monitoring approaches.

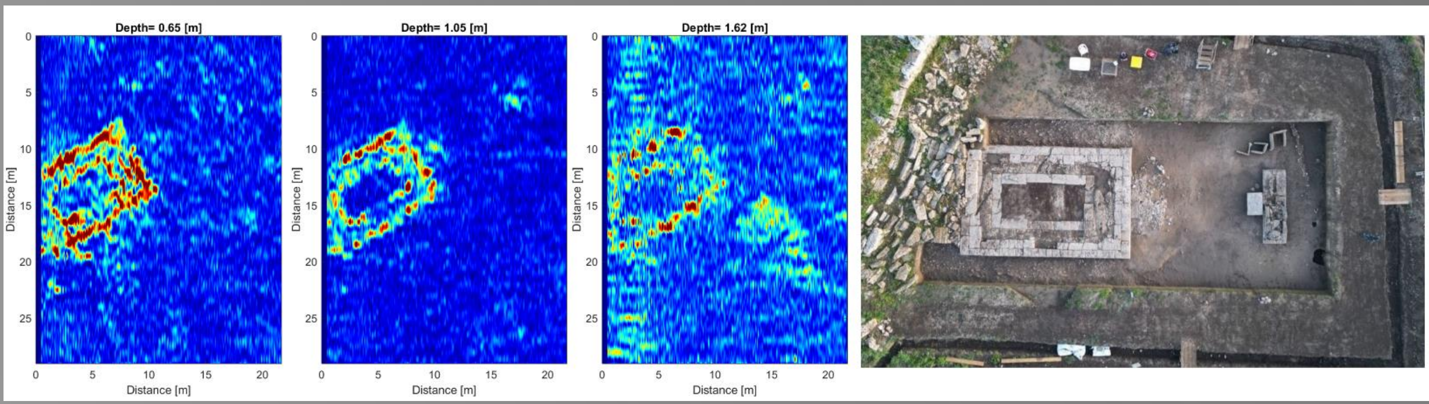
In the scientific domain of cultural heritage, non-invasive sensing techniques represent important and widespread tools for discovery, knowledge and conservation purposes from the territory scale to that of a single, precious and delicate artwork sherd.

Regarding this topic, IREA research activities tackle the exploitation of electromagnetic technologies operating in the frequency range from microwave to terahertz as tools to perform stratigraphic analysis at different spatial and resolution scales. Specifically, issues linked to the practical use of assessed and innovative systems, challenges related to data processing and image interpretation as well as aspects connected to the cooperative use of different technologies are faced thanks to the design of measurement protocols and the development of strategies enhancing the sensing capability of ground penetrating radar systems and Terahertz spectrometers.

The activities have had valuable fallouts, among which the discovery of a buried temple at the Archeological Park of Paestum, in an area devoted to agricultural activities. Such a discovery was possible thanks to the collaboration with the colleagues of the Institute of Methodologies for Environmental Analysis, National Research Council of Italy, which performed a preliminary geomagnetic survey on a wide area by detecting a restricted area, later investigated using the ground penetrating radar available at IREA. The GPR data processing through a linear microwave tomography approach developed by the IREA researchers provided clear images of the subsoil giving detailed information about the temple location and highlighting the geometry of its basement with high accuracy.

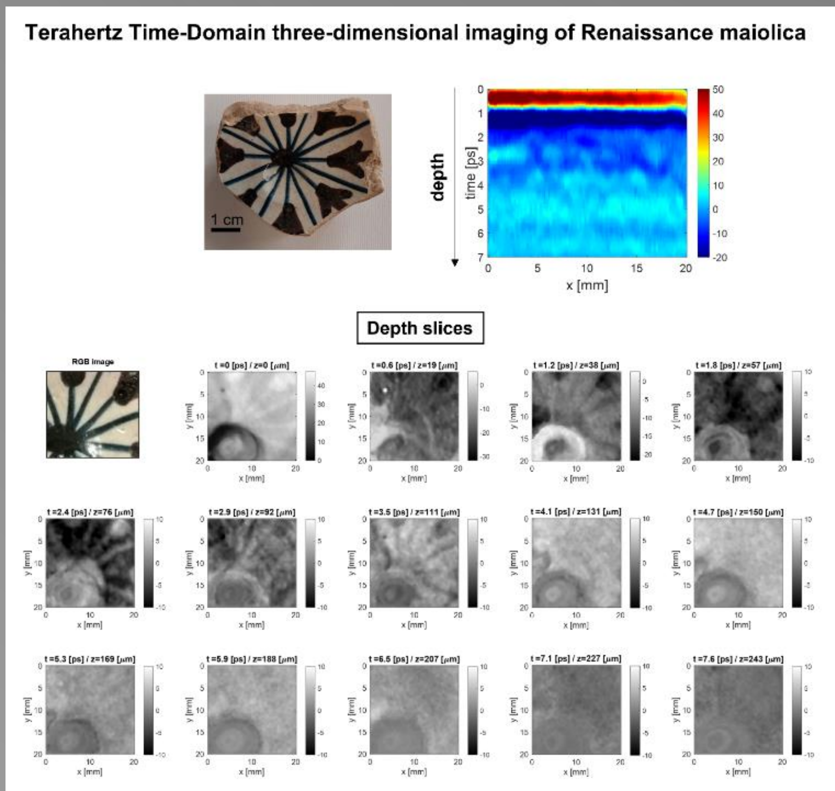
Further relevant contributions regard the stratigraphic analysis of artistic assets such as majolica, frescoes, and stone materials carried out by exploiting THz instrumentation and specifically designed measurement protocols and data processing procedures.

Thanks to the gathered skills, IREA researchers support the national node of the European Research



Discovery of an ancient temple at the archeological park of Paestum and Velia thanks to a microwave tomography enhanced GPR survey.

THz analysis of a maiolica sherd, which is part of collection of the Museo Nazionale del Bargello in Florence



Infrastructure on Heritage Science E-RIHS with regard to THz analysis. In this frame, sherds of the maiolica collection of the Museo Nazionale del Bargello in Florence manufactured between the 15th and 16th centuries in Central Italy were investigated. The performed analysis corroborates the possibility of using THz-TDI imaging, not only to discern between coloured and white areas but also to characterize the glaze structure. This latter, for the investigated sample, appears as made by an upper layer, affected by the inhomogeneous distribution of the colouring and opacifying agents as well as by the weathering action, and a bottom homogeneous layer.

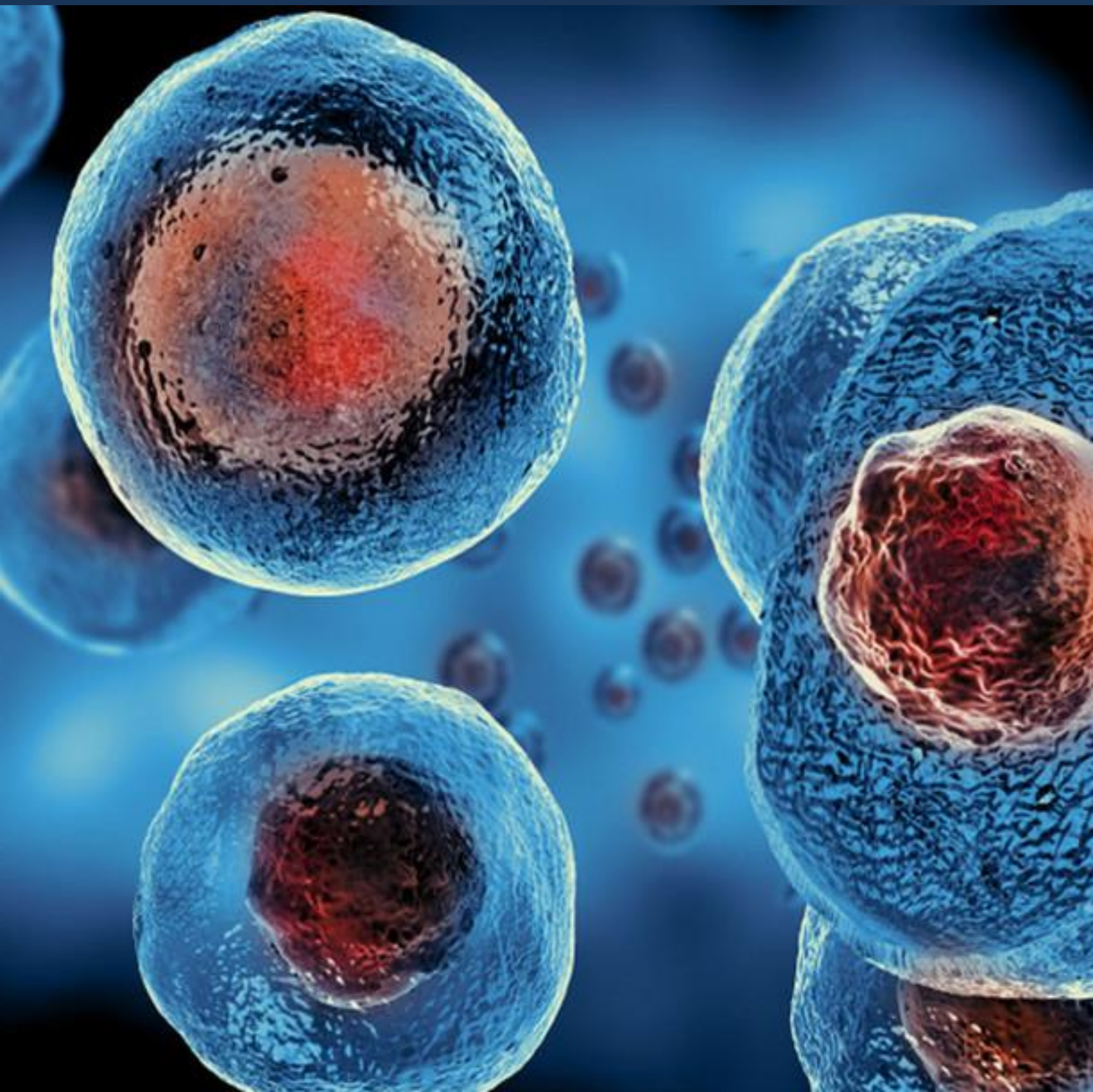
CONTACT

Ilaria Catapano

Phone +39 081-7620645

catapano.i@irea.cnr.it

HEALTH AND HEALTHCARE



The widespread diffusion of sources of electromagnetic fields (power lines, radio-TV stations, radio base stations, and mobile phones) is of great public concern for the possible health risks.

Recently, the ubiquitous presence of wireless technologies that use radiofrequency electromagnetic fields (mobile phone and wifi systems) and the evolution of their applications contributed to fueling this concern for the possible adverse effects on the health of the exposed population, above all concerning 5G technology which is perceived by some as a serious threat to public health.

The questions that many people ask are: what is the impact of electromagnetic fields on human health? Should we be concerned by them, and is there a health hazard?

For many decades, IREA researchers have been contributing to finding answers to these questions through in vitro experimental activities, review of scientific literature on the biological and health effects of electromagnetic fields, and monitoring of their background levels in internal and external environments.

On the other hand, for several years the scientific community has been interested in the use of electromagnetic fields for therapeutic and diagnostic applications in safe conditions.

In this context, the IREA research activity concerns the development of innovative diagnostic, monitoring, and therapeutic strategies based on the exploitation of electromagnetic field use at optical and microwave frequencies and high-voltage electrical impulses.

As far as medical diagnostics is concerned, the attention of IREA researchers has been focused on two specific aspects. The first one regards the realization and characterization of optical sensors that are sensitive and compact, suitable for point-of-care analysis. The second research interest is in the development of microwave imaging devices to perform a safe and non-invasive diagnosis. In particular, a technique that exploits magnetic nanoparticles as a selective contrast agent for early diagnosis of breast cancer has been pioneered by IREA. Also, a portable device for monitoring the brain of patients suffering ischemia, haemorrhage, or intracranial hematomas has been developed.

Regarding the therapy, the research activities are concerned with the study of the interaction between high-voltage electric pulses and mammalian cells to optimize the medical effects of the electroporation phenomenon. The research results have shown that the exposure of mammalian cells to high-intensity pulsed electric fields can increase the permeability of the cell membrane to substances usually not penetrating the cell (electroporation), which interact with the intracellular structures and induce death in cancer cells.

In addition, the IREA researchers are exploring the potential of microwave imaging for treatment guidance. In particular, the efforts have been addressed towards the development of a device capable of monitoring thermal ablation of liver cancer, wherein real-time information on the status of treated tissue is essential to address the clinician towards a more effective treatment.

Health risk from exposure to electromagnetic fields

Maria Rosaria Scarfì, Olga Zeni, Stefania Romeo, Anna Sannino, Mariateresa Allocca, Valentina Peluso

In the general frame of evaluating the health risk from exposure to electromagnetic fields, IREA researchers develop methodologies and technologies for exposure of mammalian cell cultures to both low-frequency magnetic fields, such as those associated with the transmission and distribution of electricity, and high-frequency electromagnetic fields, with specific reference to the fields emitted by wireless technologies (mobile phones, radio base station, WiFi networks).

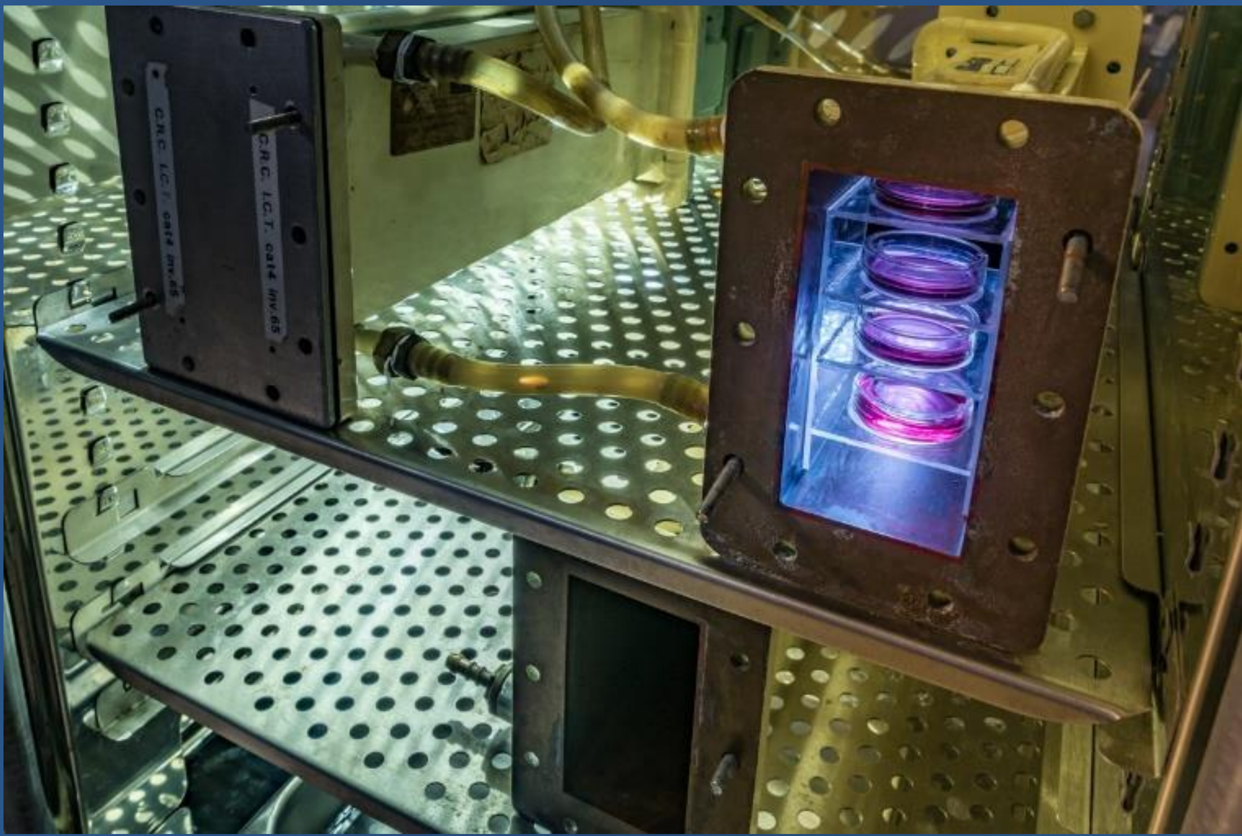
Due to the exponentially increased human exposure to electromagnetic fields emitted by wireless communication systems and the recent deployment of 5G, in the last years the activities have mainly focused on the effects of radiofrequency exposure.

Taking advantage of their multidisciplinary expertise, researchers at IREA design, realize, and characterize radiofrequency exposure systems for mammalian cell cultures under controlled experimental conditions in terms of electromagnetic and biological parameters. PC-controlled exposure systems are hosted in standard cell culture incubators to ensure the appropriate temperature conditions, CO_2, and humidity conditions inside the biological samples during exposure. Identical but not-fed exposure systems are employed to host control samples to exclude that possible effects may arise from environmental conditions inside the exposure systems and not only from radiofrequency exposure. After the exposure, mainly cancer-related endpoints are evaluated by supporting an answer to the social demand regarding the cancer development in the exposed population.

The effects of radiofrequency exposure in combination with other physical or chemical agents are also under investigation to evaluate the onset of possible combined effects. Indeed, we all are exposed to several agents, in addition to electromagnetic fields, that can cooperate to induce either adverse or beneficial effects.

At the same time, IREA researchers are involved in the critical evaluation of the literature on the effects of electromagnetic fields by participating in national and international committees (WHO, IEEE, Swedish Radiation Safety Authority, EU working groups) and contributing to releasing monographs and technical reports that are used by competent authorities for the development of guidelines for electromagnetic field exposure.

Moreover, IREA researchers have developed methodologies for monitoring electric, magnetic and electromagnetic field levels in urban and working environment. Measurement campaigns are carried out to characterize the general public and workers' exposure conditions and to verify compliance with exposure limits defined by national and international regulations. This assessment is particularly significant in sensitive areas (schools, hospitals), where the prolonged permanence of sensitive subjects like children and elders is foreseen. In this framework IREA has given a decisive contribution, in collaboration with the Institute of Methodologies for Environmental Analysis (IMAA) of the CNR, to the implementation



Radiofrequency exposure system set-up for cell cultures

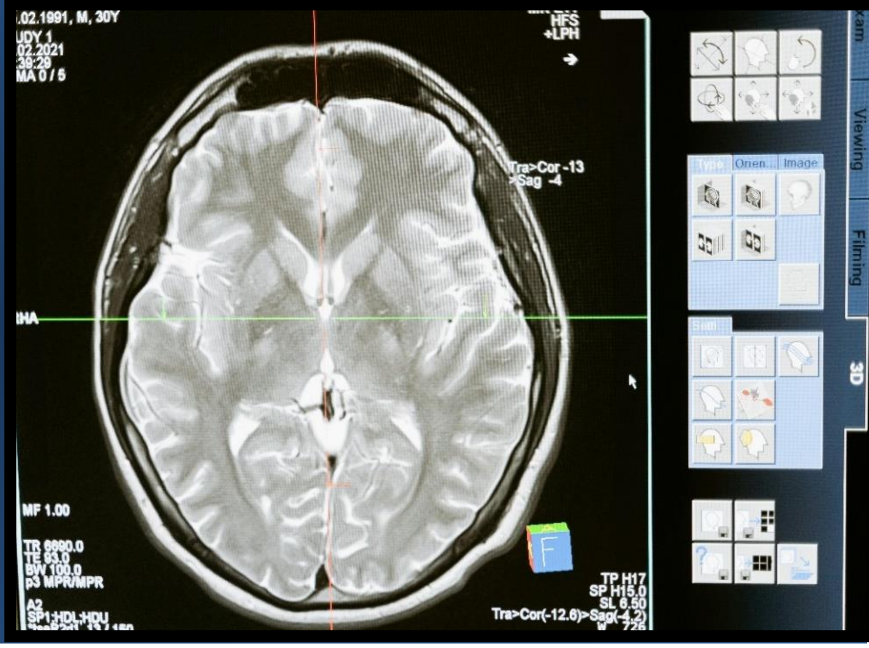
of the Regional Cadastre of the sources of radiofrequency electromagnetic fields of the Basilicata Region.

CONTACT

Olga Zeni

Phone +39 081-7620657

zeni.o@irea.cnr.it



Electromagnetic fields for medical imaging

Ilaria Catapano, Lorenzo Crocco, Gianluca Gennarelli, Giovanni Ludeno, Roberta Palmeri, Rosa Scapaticci

The non-ionizing nature of microwaves and their capability of penetrating objects, without inducing alterations or long-term risks, motivate their use for medical diagnosis and therapy and the design of technological solutions, which preserve patients by the well-known side effects of X-rays and allow a reduction of the healthcare expenses, compared for example to magnetic resonance imaging (MRI).

Several medical applications using EM fields are carried out at IREA.

So far, breast cancer diagnosis and imaging have been the most investigated application of microwave imaging, due to the initial studies on human tissues that showed a high electric contrast between healthy and cancerous breast tissues. Recent studies rebutted this initial evidence by demonstrating that the contrast between healthy and malignant tissues is quite low. This heavily impairs the diagnostic accuracy and reliability of breast cancer detection.

To overcome this issue, the EM diagnostic group at IREA has introduced a unique diagnostic technique, which exploits the joint use of microwave imaging technology and magnetic nanoparticles as contrast agents for a highly sensitive and specific diagnosis of breast cancer.

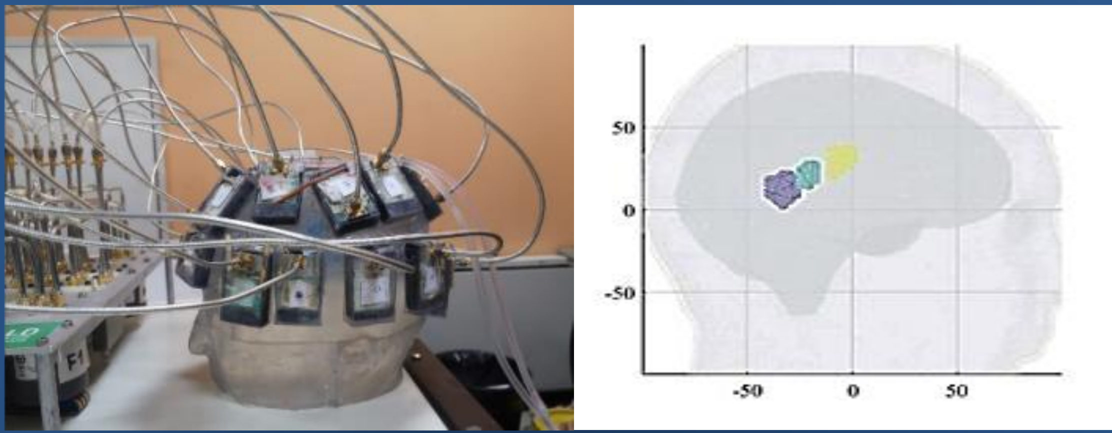
Since human tissues are non-magnetic, the selective accumulation of magnetic nanoparticles in tumoral tissues and their detection/localization would be a very specific indication of the presence of a tumour, preserving patients from ionizing effects typical of other imaging technologies.

This innovative diagnostic approach has been demonstrated with an experimental proof of concept using an ad hoc designed system and using commercially available biocompatible nanoparticles.

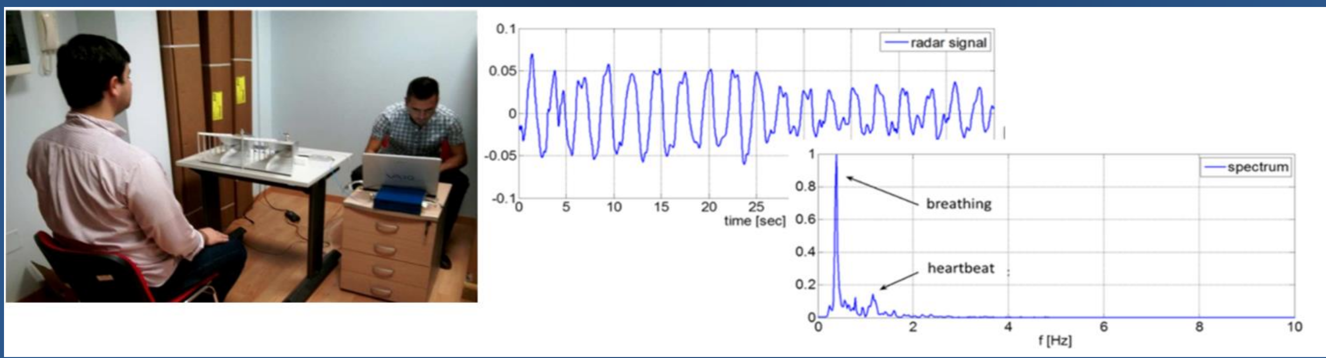
These preliminary findings not only demonstrated the actual feasibility of the technique but also characterized the amount of nanoparticles that can be detected. Currently, a 3D prototype system suitable for performing pre-clinical experiments on realistic phantoms is being installed at the IREA EM-diagnostics laboratory and will be used to provide further evidence of the potential of this novel diagnostic technique.

Some pathologies or clinical conditions require continuous patient monitoring to detect and counteract possible worsening of health conditions and to guide therapy procedures. Examples are brain stroke follow-up and thermal therapy monitoring.

In the case of brain stroke follow-up, continuous monitoring is crucial to take under control the effectiveness of drug suitable to this scope, because not portable, time-consuming, and cancerogenic (in the case of computerized tomography). To meet such a clinical need, researchers at IREA have proposed the adoption of microwave imaging to follow the evolution of stroke and provide images useful for clinicians to detect changes in the ischemic or haemorrhagic areas. The great advantage here is the possibility to develop a portable and cost-



Prototype of the Brain Stroke monitoring device developed by IREA in collaboration with Politecnico di Torino
Left panel: the prototype; Right panel: the imaging output of the device tracking stroke evolution during acute stage



Prototype of the Bioradar developed by IREA researchers for contactless monitoring of heartbeat and breath.
Left panel: the radar prototype during an experiment on a volunteer subject. Right panel: the imaging output of the device (raw data and post processed data) heartbeat and breath frequencies. The data are not related to the subject in the left panel

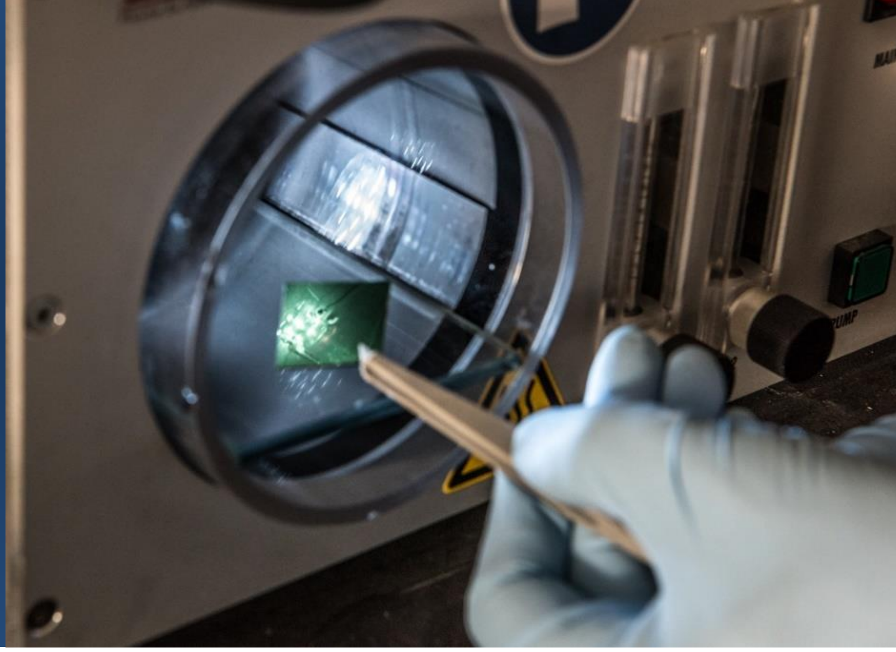
effective technology, which can be deployed in patients' beds. A prototype has been realized and tested on anthropomorphic phantoms, in collaboration with the Politecnico di Torino. Current activities are focused on the validation of the system on more complex phantoms, which is the prodromal step before the experimentation on patients.

Also, respiration and the heartbeat frequency rate are indicators for judging changes in patient health status. The design of technological solutions for low-cost contactless monitoring is of interest in all those cases wherein the sensors are forbidden, rushed or felt as annoyance and invasive. The IREA team has designed and laboratory-tested several flexible radar Doppler systems suitable for human movement tracking and real-time monitoring of the frequency rate of cardiopulmonary parameters. This radar technology is of interest for the home monitoring of persons affected by dysfunctions caused by chronic diseases, such as sleep apnea and sleep disorders, as well as the timely identification of falls or anomalous events that may indicate a sudden illness.

CONTACT

Rosa Scapaticci
Phone +39 081-7620655
scapaticci.r@irea.cnr.it

DIAGNOSTICS



Electromagnetic fields for biomedical sensing

Genni Testa, Gianluca Persichetti, Romeo Bernini

Electromagnetic fields at optical frequencies are powerful tools for detecting, analyzing, and monitoring biological substances from small molecules up to cells and tissues.

In recent years, there has been a growing demand for high-performance devices capable of performing rapid and reliable patient-level analyses, thus enabling quick and effective diagnosis and therapy compared to those in the laboratory.

In this context, using optical sensors for clinical diagnosis and therapy has several indisputable advantages, including high sensitivity and specificity, and very short response times. Another strength of the optical sensors application is the potentiality for reducing sensor size. Miniaturization promotes sensor portability, enabling real-time and point-of-care monitoring of patient clinical parameters. Size reduction also means a droplet-like sample volume for non-invasive patient treatment/diagnosis in the hospital and at home.

In this frame, the research activity carried out at IREA deals with the development of an innovative approach for the realization of compact optical sensors.

The increasing request for non-invasive, rapid and real-time point-of-care analysis pushes the researchers to develop new miniaturized sensor platforms, the so-called lab on chips (LOCs) or micro total analysis systems (µTASs). Basically, an optical LOC is a sensing platform that integrates a microfluidic system for sample treatment and a photonic structure for sensing.

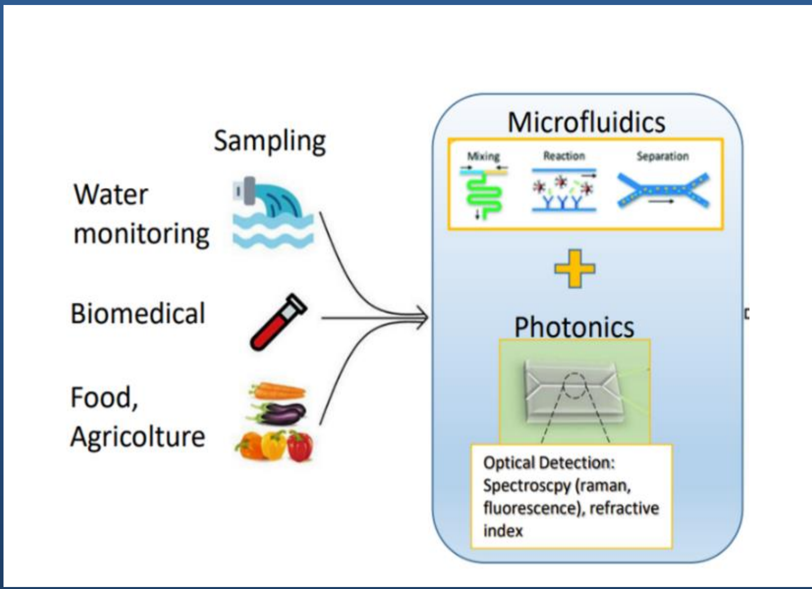
Thanks to the recent advances in microfluidic technologies, several analytical steps on sample volume usually performed at the lab level, like concentration, mixing, and targeting, can be implemented autonomously on the sensor platform. In addition to the advantage of reducing the overall device size, microfluidic integration can improve the repeatability and the time response of the device by allowing fine control of the sample flow.

By using a soft lithographic technique together with a computer numerically controlled milling machine, researchers at IREA have developed several microfluidic devices like mixers, flow cells and a cytofluorimeter.

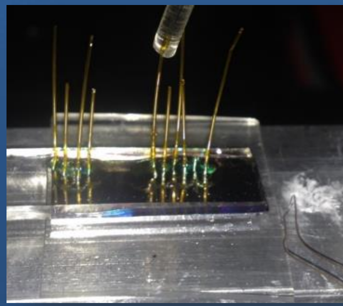
In particular, IREA researchers collaborated on the development of a drug monitoring point-of-care-testing optical device for the measurement of immunosuppressants and related metabolites in transplanted patients. Moreover, they developed and validated an optical LOC prototype based on surface plasmon resonance for SARS-CoV-2 detection in biological samples.

Miniaturization can offer a host of relevant advantages, but the reduction of interaction length (that is caused by downscaling the physical length of the sensing path) can strongly weaken the sensor sensitivity. One possible solution to overcome this limitation is to improve the optical interaction between the light and the sample by developing new photonic solutions.

In this frame, IREA researchers have designed and



Scheme of an optofluidic device for liquid analysis



High perfomance polymeric Fabry-Perot optofluidic cavity

Optofluidic integrated ring resonator chip

built a liquid core optofluidic waveguide as a building block of an integrated optical platform for sensing applications. In a liquid core waveguide, fluid provides the means to guide the light, thus enabling a maximized optical coupling across the entire photonic structure. Using this approach, IREA researchers developed high-performance optical devices for biosensing applications and new methodologies to integrate microfluidic functionalities on a chip without affecting the optical performance of the devices.

Furthermore, a hybrid integration of silicon-based photonic structures shaped by optofluidic waveguides and polymeric microfluidic devices on the same sensing platform was successfully developed. By employing this strategy, an ultra-sensitive biosensor based on a liquid core waveguide for the optical detection of specific sepsis biomarkers was realized.

Although silicon-based materials posses excellent optical properties, nowadays other materials are going to become preferred to lower the cost and simplify the fabrication of optical LOC sensors. In particular, polymers are very promising materials thanks to their low costs, high versatility of material properties, and the possibility of being processed by low-cost manufacturing processes like a micro-milling machine.

Using polymers, researchers at IREA have designed, fabricated and validated high-performance optical sensors based on resonant optical cavities. Miniaturized optical cavities like ring resonators and Fabry-Perot are considered among the more sensitive photonic structures available for sensing at the micron scale.

In this context, IREA researchers also developed polymeric optical sensors based on ring resonators. The sensor integrates a polymeric microfluidic cell to control the flow rate of the liquid sample on the sensor surface. Microfluidic integration was achieved by developing an innovative approach to speed the rate of transport of the analytes towards the sensing region, which is typically limited by the diffusion phenomenon at the microfluidic scale. The biosensing capability of the device was demonstrated by sensing BSA protein and label-free antibody-antigen binding on the sensor surface. Moreover, innovative all-polymeric optofluidic Fabry-Perot cavities have been developed. With this approach, the sample flows and the probing light are confined in the cavity for a maximized optical interaction. Current activities concern the implementation of the cavity in biosensing applications.

CONTACT

Genni Testa

Phone +39 081-7620643

testa.g@irea.cnr.it

THERAPY

Electromagnetic fields for advanced and guided treatments

Maria Rosaria Scarfi, Olga Zeni, Stefania Romeo, Anna Sannino, Mariateresa Allocca, Lorenzo Crocco, Rosa Scapaticci

Electroporation (EP) is a biophysical phenomenon consisting of the increased permeability of cell membranes by applying high-voltage electric pulses. EP is currently used for cancer therapy to enhance the uptake of chemotherapeutic drugs by cancer tissues, with reduced side effects for patients compared to chemotherapy alone.

Researchers at IREA develop technologies to generate and deliver high-voltage electric pulses to mammalian cells and to study the interaction with cellular structure. The final goal is to optimize the already available strategies and develop new protocols to enlarge the applicability of such a technology.

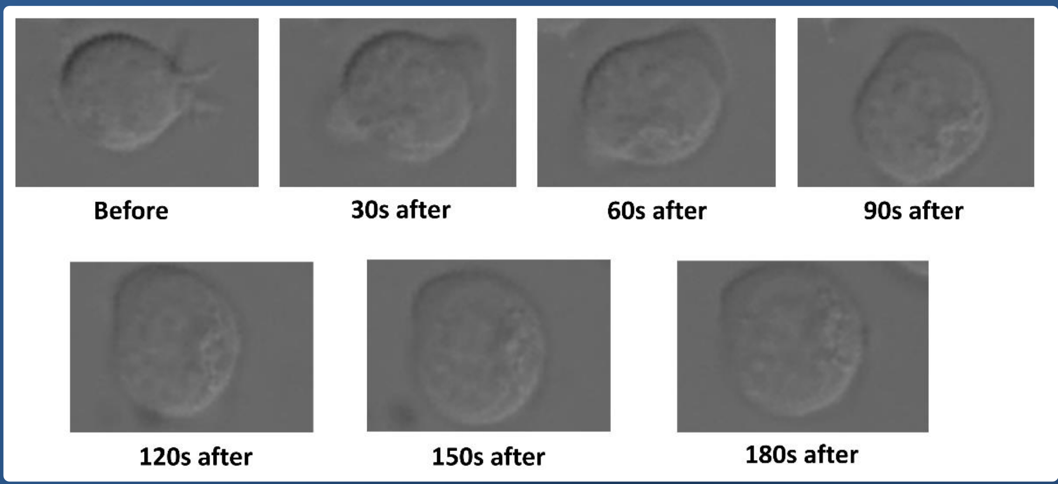
More recently, investigations on electroporation in the presence of calcium have been launched, since the massive entrance of calcium in cancer cells by EP has been demonstrated to induce cell death in the absence of side effects typical of chemotherapeutic drugs.

In collaboration with the University of Salerno, the activities of IREA researchers also involve the electrophysical modelling of EP phenomenon by employing numerical methods, as an aid in the interpretation of in vitro results and to support and optimize the experimental design.

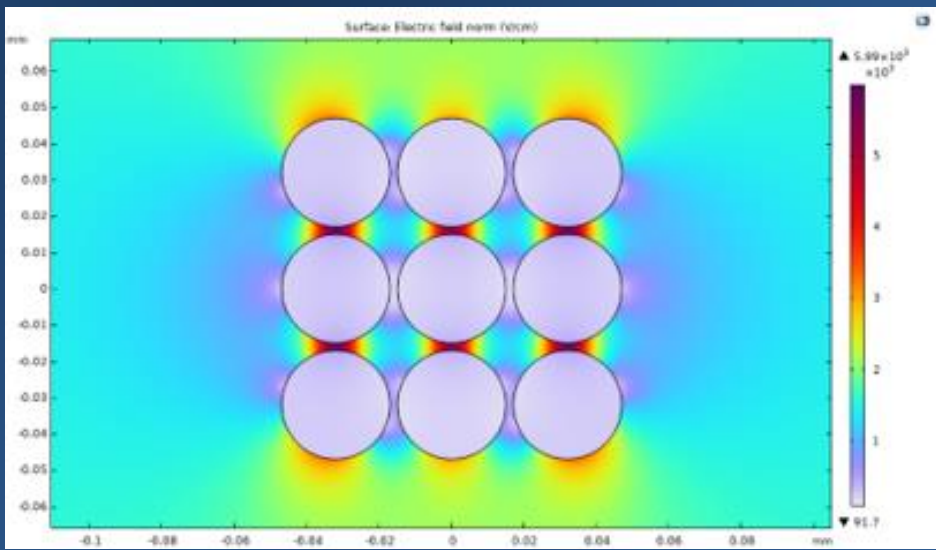
A different monitoring application of microwave imaging is image guidance for thermal therapy, in particular microwave ablation of liver cancer. This therapy consists of delivering microwave power through an ad hoc designed applicator that exploits dielectric hysteresis due to the interaction between the radiated microwave field with the surrounding tissue to produce heat. Although more efficient than radiofrequency ablation, because capable of treating large volumes in a shorter time, microwave ablation shows a low control on the temperature reached in the treated tissue. Hence, an imaging technique able to promptly inform the clinician that therapeutic temperature has been reached in the target tissue while assuring a safe temperature in the healthy region would revolutionize the treatment protocols of liver cancer. Microwave imaging has been proposed at IREA and numerically validated the possibility of guiding microwave ablation using microwave imaging. A preliminary proof of concept experimentation has been designed and realized.

An increasingly important aspect in modern medicine is the use of imaging techniques to guide the clinician in the precise administration of the treatment. This is for instance the case of microwave ablation of liver cancer. In this treatment, microwave power is delivered in the tumor through an ad hoc designed percutaneous applicator that exploits dielectric hysteresis to locally produce heat. When the temperature increase achieves the therapeutic value, the surrounding cells are killed.

Microwave ablation is more efficient than radiofrequency ablation, because it can treat larger



Cell swelling under pulsed electric field exposure



Electric field distribution in cell aggregate exposed to electroporation pulse

volumes in a shorter time. However, it requires a proper control of the temperature, to avoid over-treatment and other complicacies. Accordingly, the availability of an imaging technique able to promptly inform the clinician that therapeutic temperature has been reached in the target tissue, while assuring a safe temperature in the healthy tissue, would boost the effectiveness and the efficiency of liver cancer treatments.

In the framework of an ongoing collaboration with Sapienza University of Roma, the IREA researchers have proposed the use of microwave imaging to pursue this task. In particular, the goal is to develop a device that can sense the abrupt changes in the electromagnetic properties of ablated tissue (which are due to significant reduction in water content) and proved a map of the temperature changes in the treated region. The initial studies on such a technology are ongoing and a preliminary proof-of-concept experiment has been implemented and performed. Currently, the efforts are focused on the development of a prototype to perform validation experiments in a clinically relevant, yet controlled, scenario.

CONTACT

Stefania Romeo

Phone +39 081-7620660

romeo.s@irea.cnr.it

SCIENCE AND SOCIETY

Science and society are deeply linked, as each has a profound influence on the other. Science evolves in response to society's needs, and scientific discoveries fuel technological innovation, drive economic growth, and improve the quality of our lives. Science also shapes our understanding of ourselves, expanding our worldview.

However, the relationship between science and society is not without complexities. Scientific progress often raises ethical dilemmas and societal concerns, forcing us to address questions of responsibility. Issues such as genetic engineering, artificial intelligence, or climate change demand thoughtful consideration and careful deliberation as we face the ethical, social, and environmental implications of scientific advancements.

For this reason, the dissemination of scientific knowledge is essential to facilitate informed decision-making and promote public understanding. Science communication plays a crucial role in bridging the gap between experts and the general public, translating complex concepts into accessible language, and enabling individuals to make evidence-based choices in their daily lives.

Equally important is to question the social role of the scientific community and study new models of public communication that go beyond the mere objective of disseminating research results and aim at the active involvement of the various actors both in the communication process and the production of knowledge itself. The scientific community needs to rethink its social role and establish new relationships with society to generate responsible research practices.

At IREA both aspects are taken into consideration. On the one hand, there is great attention to scientific communication and dissemination, developed through the website and institutional social channels, editorial products, informative videos, press releases, informative articles, participation in dissemination events, and activities for schools.

On the other hand, public communication is a research topic that, using the tools and methodological approaches typical of the human and social sciences, wants to investigate the role of the scientific community in the interaction between knowledge and society.

SCIENCE AND SOCIETY

Communicating Science: IREA's commitment to public engagement and innovation

Public communication of science is an essential activity for a research institution. It is a responsibility and a strategic imperative. By actively engaging with the public, scientific institutions can promote transparency, garner support, disseminate knowledge, attract collaborators, address societal concerns, counteract the spread of misinformation, promote trust in scientific institutions, and ultimately fulfil their mission of advancing scientific understanding and improving the human condition.

IREA pays close attention to communication and dissemination activities as well as to scientific education initiatives aimed in particular at schools.

The Institute participates in many science dissemination events. These are excellent opportunities to share research outcomes, discoveries, and innovations with a broad audience through laboratories, conferences, seminars, and exhibitions.

Among these is the *European Researchers' Night*, the event promoted by the European Commission since 2005 to bring science closer to the general public, raise awareness among the community of the importance of innovation and research for collective well-being, and increase the interest of younger people in scientific professions.

IREA has also participated for many years in the *Genoa Science Festival*, one of the most important events for the diffusion of scientific culture in Italy, and *Futuro Remoto*, the first European event for the diffusion of scientific and technological culture, which has been organized by Città della Scienza in Naples since 1987.

Starting from 2021, participation in these events has been carried out together with the other CNR Institutes of Campania, which this year created a network for scientific dissemination, named CREO (Campania REte Outreach), to encourage coordinated and interdisciplinary participation in the main dissemination events.

As part of the celebrations for 100 years of CNR, IREA contributed with the CNR Institutes of CREO to the realization of the online game entitled "100xCNR100", 100 questions for the 100 years of the CNR, combined with an interactive book focused on the history of the CNR and its research. The aim was to bring the public, especially the new generations, closer to the largest Italian research institution, which has been the constant reference, as well as one of the makers, of the country's scientific and technological progress over the last 100 years.

Within the framework of the CNR Centenary, IREA also realized a multimedia exhibition of spectacular Earth Observation satellite images, entitled “Rainbow and beyond: the Earth seen from space”. The wonder aroused by the environments of our planet contributed to making the visiting public understand the potential of the use of remote sensing techniques for the study and monitoring of the environment and the cutting-edge remote sensing applications and techniques developed by CNR-IREA researchers.

IREA dedicates many of its activities to schools, organizing seminars or visits to its laboratories for

IREA at the European Researchers' Night 2023

IREA with students during a PCTO project

students and carrying out PCTOs, projects to acquire new skills and develop the ability to orient oneself in choosing a study or work path.

In 2023, IREA contributed to the first edition of "BARIcode", a new Scientific Festival whose name refers to a new cultural code of sciences that must establish a relationship of exchange and dialogue with society carried out through science dissemination activities, knowledge transfer and generation of impact on the territory. The Institute organized and coordinated the Educational Workshop “Let's put down roots” aimed at pupils of primary schools to introduce children to the world of scientific research through practical experiences guided by CNR researchers. Moreover, IREA researchers animated the Laboratory "From the Earth and the sky: interpreting the images of planet Earth acquired from space", a series of recreational and educational activities to introduce young students to the concept of Earth Observation.

The Institute is also very active in promoting equal opportunities in scientific careers. In this context, since 2022 IREA has participated in the “International Day of Women and Girls in Science”, promoted by UNESCO and celebrated on 11 February to overcome stereotypes and prejudices that still weigh heavily on the choice of scientific-technological studies by women and remember how women's careers are still often an obstacle course today.

In 2023, IREA joined the social campaign "Give a selfie for Women at Cnr", a series of selfies of female researchers, technicians and technologists, accompanied by a brief description of the activities carried out and their interests, posted over the course of a year on the social profiles of the CNR institutes involved in the initiative. In this way, we attempted to normalize the vision of women in the world of research and to demonstrate to girls and women interested in STEM disciplines (science, technology, engineering, mathematics) that careers in these fields represent a real and concrete possibility. The selfies, published on the social platforms of the Institutes participating in the initiative throughout 2023, were collected in the video "300x100 protagonists for research", which was shown on 18 November 2023 in Rome during the CNR Centenary celebration event.

The dissemination of knowledge resulting from research activities is also essential for interacting with the productive world and promoting industrial innovation, generating new jobs and greater well-being, thus contributing to the economic and social development of the country. Also on this front, IREA is constantly engaged by participating with its researchers in events for innovation and the promotion of collaborations between research and businesses, such as *Innovation Village, Smau Napoli*, and *Mediterranean Aerospace Matching.*

CONTACT

Maria Consiglia Rasulo

Phone +39 081-7620618

rasulo.mc@irea.cnr.it

SCIENCE

AND SOCIETY

Transdisciplinary approaches to knowledge production and sharing

Alba L'Astorina, Lucia Maria Laurenza, Gloria Bordogna, Laura Criscuolo

The changes that have taken place in recent decades in the production of knowledge and the many threads that now link science and society expose researchers to increasingly frequent relations with the 'outside' world, which imply the use of channels, languages, objectives, methods and levels of engagement that differ according to the subjects with whom one interacts. Furthermore, the complex socio-environmental issues we face today, such as global warming and climate change, loss of biodiversity, plastic pollution, etc., highlight the limits of specialised science and the need for a new social contract between science, society and politics. The scientific community needs to rethink its social role and establish new relationships not only with society but also with ecological systems in order to develop responsible research practices, inspired by the pillars of Responsible Research and Innovation (RRI), capable of producing relevant knowledge and aiming at the active involvement of interested stakeholders.

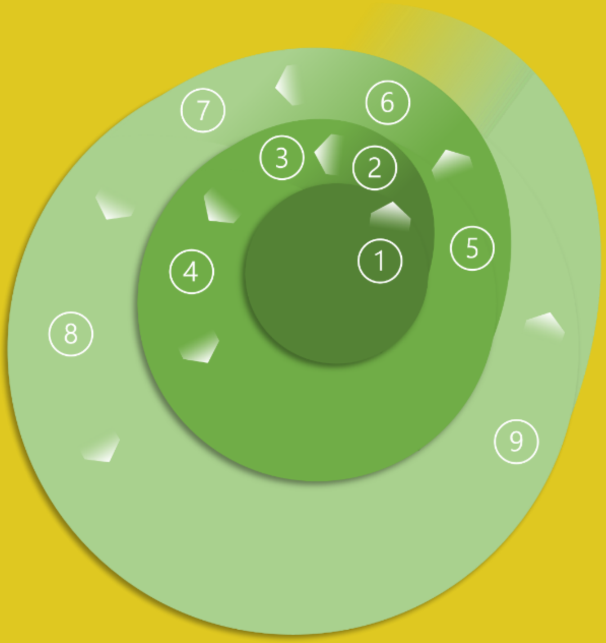
The public communication of science is an essential activity for a research institution, both as a means of valorising research activities and disseminating knowledge. But it is only one stage in the broader process of generating, validating, sharing, and applying knowledge. Such a process does not take place in a vacuum, but in a complex social system that influences the ways and means of communication as well as the choice of content.

Science communication is both a practice and a research topic that has been studied for many years at IREA by the 'Public Communication of Science' group, mainly based in Milan. In recent years and with the enlargement of the group, the scientific focus shifted more and more towards widening participation, both in communication and in the production of knowledge, and the name of the activity changed to 'Transdisciplinary theories and practices of knowledge production and sharing'. Indeed, our group is multidisciplinary, including people from both hard sciences (earth and particle physics) and social sciences (anthropology, sociology, social studies of science, science communication).

The topic is considered both as a concrete institutional communication intervention and as a research area. In the first case, communication is developed through the institutional website and social channels, as well as within the research projects. In the second case, public communication is research itself, using the tools and methodological approaches typical of the human and social sciences to investigate the role of the scientific community in the interaction between knowledge, environment and society, and its narratives on complex socio-ecological issues. The topics covered include all areas in which scientific knowledge operates, from those related to the impact of science on social life to the opportunities for access to research data and the sharing and production of new knowledge.

Another important point revolves around a vision of

1	Initial project design Team training and testing
2	Involvement and selection of extended team
3	Extended team training
4	Renegotiation of project design and results Testing of tools and procedures
5	Involvement of local citizens, associations, agencies Site inspections and selection
6	Knowledge and insight meetings Training of extended community
7	Renegotiation of project design and results
8	Experiment performance
9	Sharing of results and discussion



	Original research team	Research and Art careers: Social Science, Science Philosophy, biology, agronomy, physics, Data Science, ICT, Citizen Science, Antropology, Science Communication, Education, Visual and Performative Art
	Extended research team	Early research career from several disciplines and provenances
	Extended research community	Private citizens, public agencies representatives, local associations representatives

social sectors – science, decision-makers, (democratic) society, market, and environment (the so-called 5ple helix) – as hybridized. These conceptual developments lead to a broadening of the category of knowledge producers, pointing to the inclusion of actors who don't produce codified, textbook knowledge, but relevant knowledge nonetheless.

Underlying all these strands of research is an overarching rethinking of the nature of knowledge and its embodiment in society (e.g. the post-normal or co-production models and citizen science). If we focus on the research context, we can see how some points come already to the surface, both with regard to positioning in society (what should the state finance? how do we relate to the territory?), communication models (do we share culture? do we dialogue critically, as equals?), and the very physiognomy of knowledge.

The aim is twofold: on the one hand, to observe and analyse the research and public communication practices of the community in order to reconstruct skills, values, expectations, models of relations with society and narratives of the actors involved; on the other hand, to experiment with transdisciplinary practices that allow for greater involvement and conscious and responsible participation of the various subjects in the scientific and public debate through increasingly hybrid and participatory experiences, at the boundaries of individual social the knowledge that each individual brings to the table.

The problem is most inescapable in the case of the so-called 'complex and controversial socio-environmental issues': hey lie on the borderline between different interrelated disciplinary and social fields in which different social actors have interests; the social dimension is inseparable from the scientific dimension. We experience the frustration of our ability to respond (playing, as it were, with one of the original meanings of the word responsibility). What can be done? In recent decades, some have begun to think that if the answer is too difficult, perhaps the question is wrong. Or, at least, posed in a way that it does not lead to a meaningful, effective, decisive answer.

CONTACT

Alba L'Astorina

Phone +39 02-23699281

lastorina.a@irea.cnr.it

ANNEX

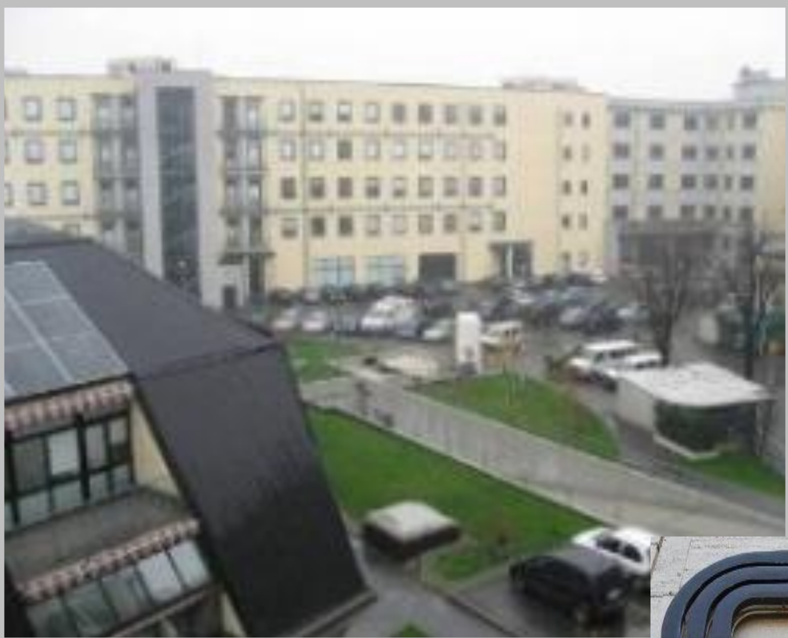
Publications

IREA publications of the last five years

All IREA publications

Publications in scientific journals

Publications in scientific conferences




Consiglio
Nazionale delle
Ricerche
Centro
Rilevamento
Ambientale
Stazione Sperimentale
di Sirmione
EUGENIO ZILIOLI

CONTACTS

IREA has its headquarters in Napoli and two other locations, in Milan and Bari.

Moreover, in Sirmione del Garda (BS) there is the Experimental Station "Eugenio Zilioli" where research activities focused on remote sensing of water quality and dissemination and environmental education activities are carried out. Since 2014, it is part of the NASA AERONET Site.

Napoli Headquarters

IREA-CNR
Via Diocleziano 328
80124 Napoli (Italy)

Phone: +39 081 7620611
Fax: +39 081 5705734

mbox@irea.cnr.it

wwWWWnr.it

@CnrIrea   Cnr-Irea

Milano Location

IREA-CNR
Via A Corti, 12
20133 Milano

Phone: +39 02 23699595
Fax: +39 02 23699300

milano@irea.cnr.it

Bari Location

IREA-CNR
Via Amendola, 122/D
70126 Bari

Phone: +39 080 5929429
Fax: +39 080 5929460

responsabile_bari@irea.cnr.it

Experimental Station "E. Zilioli"

Sirmione Punta Staffalo n. 15
25010 Sirmione del Garda (BS)

Phone: +39 030 916556
Fax: +39 030 916556

Administrative Team

Napoli

Generoso Sole
sole.g@irea.cnr.it

Francesca di Matteo
dimatteo.f@irea.cnr.it

Elena Palma
palma.e@irea.cnr.it

Nadia Russo
russo.n@irea.cnr.it

Bari

Maria Mottola
mottola.m@irea.cnr.it

Cinzia Loporchio
loporchio.c@irea.cnr.it

Milano

Roberta Pozzi
pozzi.r@irea.cnr.it

Technical Team

Napoli

Simone Guarino
guarino.s@irea.cnr.it

Ferdinando Parisi
parisi.f@irea.cnr.it

Bari

Giuseppe Camporeale
camporeale.s@irea.cnr.it

Sergio Mari
mari.s@irea.cnr.it

Milano

Simone Lella
lella.s@irea.cnr.it

Salvatore Mangano
mangano.s@irea.cnr.it

Francesco Paolo Mastromauro
mastromauro.f@irea.cnr.it

Printed in October 2024