Large-scale, real-time monitoring of Soil Moisture dynamics with Cosmic Rays

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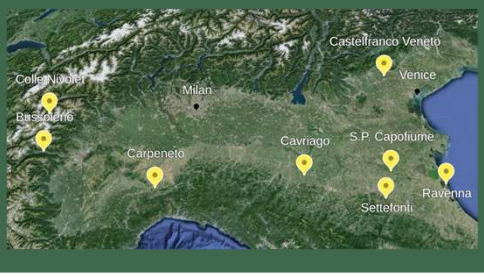
INTRODUCTION

The availability of soil water resources is regulated by soil features such as texture, structure and soil organic content. It is challenging to establish the expected water reservoir dynamic boundaries, due to soil natural complexity which develops significant variability even within small areas.
A solution to this issue is Cosmic-Rays Neutron Sensing (CRNS). It offers the capability to monitor the actual water content dynamics of an entire field year-round, using a single non-invasive sensor. Importantly, CRNS averages over soil variability, positioning itself at a spatial scale that bridges the gap between point measurements and satellite data[1]. Information obtained by CRNS can be integrated with other techniques such as point-scale measurements, sampling campaigns and satellites passes. When combined with pedological knowledge of the sites, this provides a more comprehensive and reliable picture of water content dynamics at different scales. This approach enhances our understanding of soil water resources and informs better management strategies.

CRNS is based on the detection of neutrons, particles naturally flowing from space and strongly interacting with water molecules. The rate of neutron counts by a detector placed above ground is correlated to the water content in the soil within a volume spanning up to a dozen hectares extension and up to 50 cm depth.

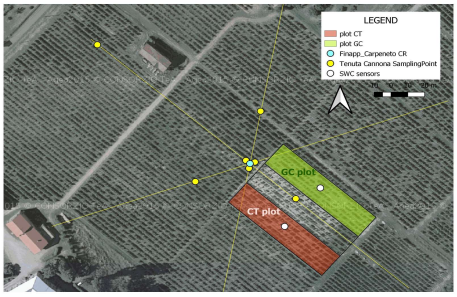
Finapp has developed and patented a light and compact detector suitable for CRNS applications on field. Eight Finapp probes in Northern Italy have been included in this study. They include, among others, a forest site, a mountain site and the ARPAE network of 4 probes.

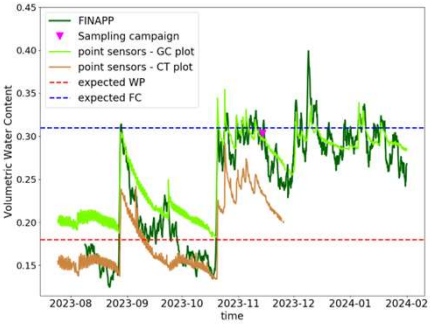


Comparison with point probes in a complex site

The Finapp CRNS probe, located at the Tenuta Cannona site (Carpeneto, AL), encompasses various plots of a vineyard within its footprint. These include a Grass Cover (**GC**) plot and a Conventional Tillage (**CT**) plot, where Volumetric Water Content (**VWC**) is locally monitored by sets of point-scale probes. The footprint also covers areas of Alternative Cover Crop.

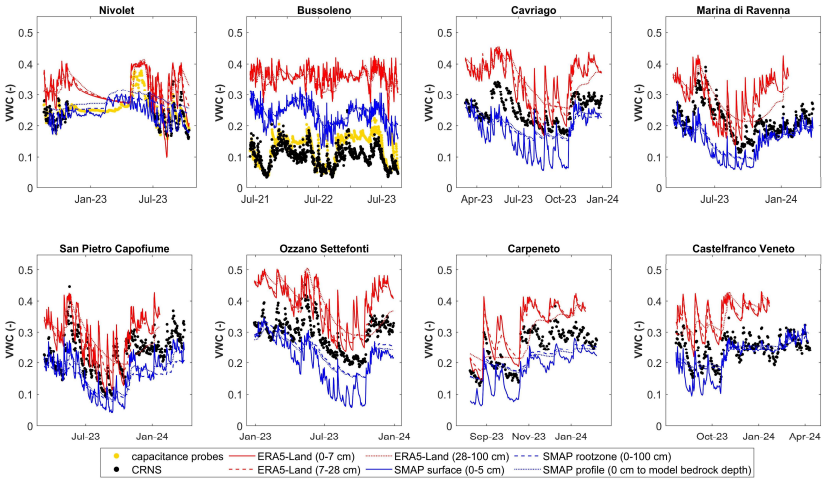
- **The VWC trends** registered by the punctual sensors shows a high variability between the plots. The areal CRNS data seems to align better with one or another point trend during different periods.
- **CRNS** captures the VWC dynamic of a large area. This can be assessed through a distributed **soil sampling campaign** (represented by yellow points in the scheme) and applying a weighted average of the VWC values of the collected known volume samples (campaign results are represented by the magenta triangle in the plot).
- The **expected hydrological dynamical range** for the site is reported in terms of Wilting Point and Field Capacity thresholds (dashed lines in the plot).





Assessment with ERA5-Land and SMAP

The **VWC measured from CNRS** at all the sites **is compared with estimations from satellite-based data of SMAP[2] and ERA5-Land[3]** (having spatial resolution of approximately 9 km) in order to assess how it can be representative of a wider area.



- **Finapp dynamics** are generally **in agreement with satellite trends**, suggesting that the precipitation dynamics affecting a larger area (about 80 km^2) are not significantly different from those affecting the CRNS footprint (hundreds of m^2). This holds especially for the agricultural sites in the plains (all presented sites, except for Bussoleno and Nivolet).
- **In all the agricultural sites, Finapp values are halfway between ERA5-Land** and **SMAP**. A general overestimation of VWC by ERA5-Land with respect to SMAP was already reported by Lal et al[4] and needs further investigation.
- Two sites appear as outliers: **Colle del Nivolet** (high-altitude mountain site, covered with snow during winter) and **Bussoleno** (rugged terrain covered by forest). In both sites the VWC by Finapp CRNS is in good agreement with point-scale capacitance probes (CPS) measurements.
- In the Bussoleno site, both satellite-based trends **report higher VWC** compared to the local measurements. A decoupling between VWC values from ERA5-Land and SMAP in forested areas was already reported by Xing et al[5]. In addition, Lal et al[4] found that the mismatch between SMAP and ERA5-Land is greater in highly vegetated areas, such as the Bussoleno forest.

CONCLUSIONS AND PERSPECTIVES

The comparison between point-scale measurements, CRNS and satellite data provides an insight into the relation between VWC measurements at different scales. Preliminary results from the Tenuta Cannona site highlight the differences between point VwC in differently managed lots and suggest that CRNS captures the prevalent dynamics. A larger scale representativity of Finapp data emerges in most sites and opens to the promising possibility of using them as ground reference to improve satellite-based products, especially in the challenging case of forestry sites.

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