Emerging trends in the territorial and rural vulnerability-vibrancy evaluation. A bibliometric analysis

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Connecting Scales of Soil-Moisture Measurements by Cosmic Rays Neutron Sensing

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Abstract

Cosmic Rays Neutron Sensing (CRNS) emerged among proximal sensors as a reliable option for filling the scale gap between point probes and remote sensing.

CRNS consists in detecting ambient neutrons close to the land surface, generated by the flow of high-energy particles from space. By placing a non-invasive detector above ground, the albedo of ambient neutron is collected. Thanks to the strong absorption of epithermal neutron by hydrogen in water molecules, the neutron count rate can be converted into a value of Soil Moisture (SM) averaged in the large volume of soil probed by the neutrons.

A single CRNS probe can effectively monitor SM in an area up to a dozen hectares and a depth up to 50 cm, which defines an intermediate spatial scale in between point measurements and remote sensing, while also granting continuous measurement and a sub-daily temporal resolution. The measurement provided by a single probe can be representative of a whole agricultural or environmental monitoring site.

However, it is the synergy between different technologies across scales that can boost the overall value of measurement systems. Local measurements like point-scale probes and soil sampling campaigns, together with a deep knowledge of the site, allow to interpret and validate the CRNS observed dynamics and in turn validate hydrological modelling. On the other hand, the horizontal spatial scale of the CRNS footprint is fairly comparable with remote sensing pixel, opening the possibility to interpolate data between satellite passes and, if a CRNS network is available, between multiple ground validation points.

We here report observations from a set of sites in Northern Italy where CRNS probes manufactured by Finapp were installed. The sites span a variety of landscapes, soils and land uses (including agricultural, vineyard, forest, high-altitude grassland) and are monitored by a variety of approaches including capacitive probes, manual sampling campaigns, hydrological modelling (CLM5 and HYDRUS-1D model), and remote sensing products (ERA-5-Land, SMAP).

The observation and comparison of different study cases show how the integration of CRNS with the other techniques can provide a more complete and reliable understanding of soil moisture dynamics at a local scale, making it possible to extend these understandings to a regional scale.

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The Finapp detector

Being based on ZnS scintillator material, the Finapp detector can detect and discriminating both neutrons and muons (patented feature).

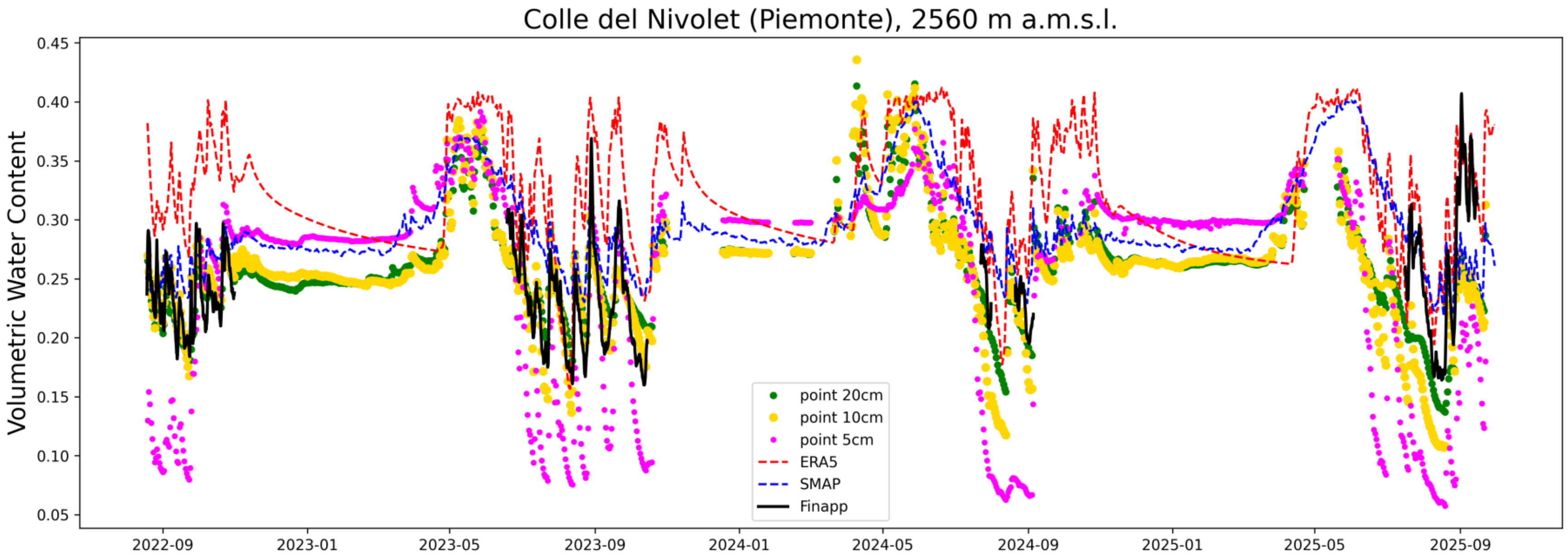
The scintillator material is relatively cheap and comes in solid thin sheets, that are sandwiched with slabs of lightguides to obtain a light, compact and safe detector.

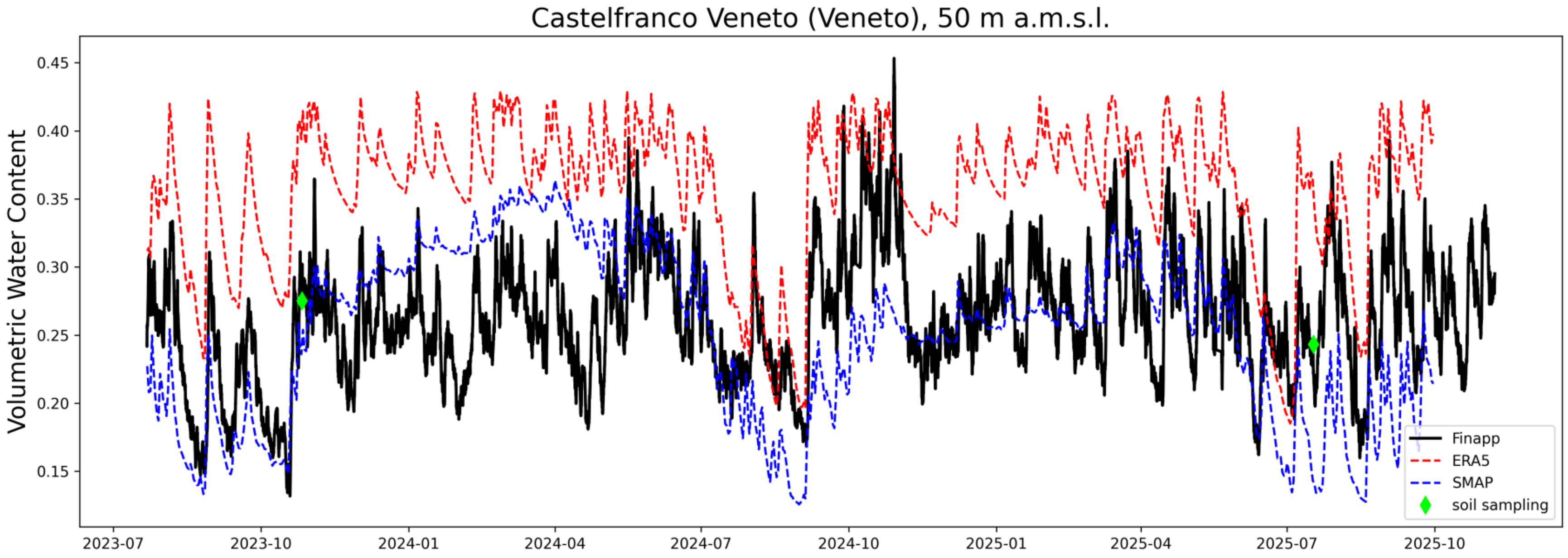
The sites

Site	Soil use	CRNS activation	Local measurements
Bussoleno (DIST)	Broadleaf forest	2020	Point-scale probes
Colle del Nivolet (DIST)	Grassland	August 2022	Point-scale probes
Villanova Solaro (ARPAP)	Agricultural (corn)	March 2023	Soil sampling
Chevrere (DIST / CVA)	Conifer forest	May 2023	Point-scale probes
Castelfranco Veneto (ARPAV)	Grassland	July 2023	Soil sampling
Tenuta Cannona (STEMS / DIST)	Vineyard	August 2023	Soil sampling; point-scale probes
Bonisiolo (ARPAV)	Agricoltural (corn/soy, covercrops)	April 2024	Soil sampling; point-scale probes

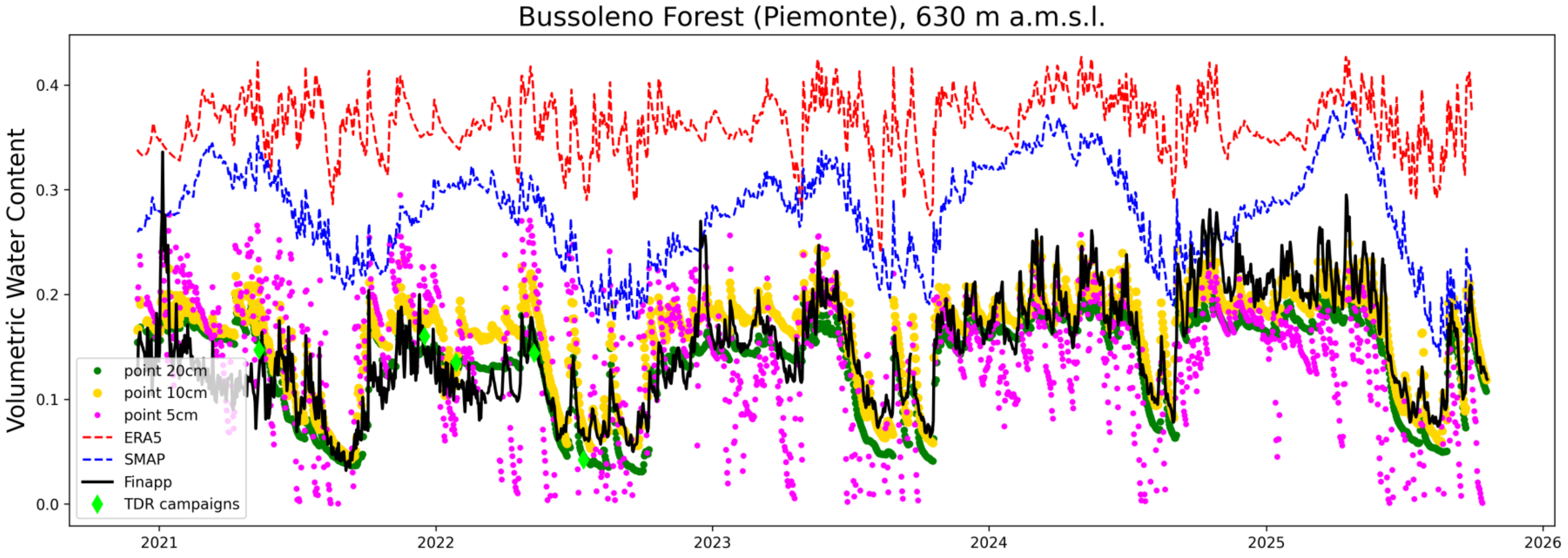

Legend
SMAP-L4 pixels
ERA5-Land pixels
Main cities
Study sites with CRNS
Forest
Grassland
Agricultural area
Regional administrative boundaries
Background: Google Satellite (c)
Aosta
Chevrere
Nivolet
Milano
Bussoleno
Torino
Villanova Solaro
Tenuta Cannona
Castelfranco Veneto
Bonisiolo
Venezia
Bologna
0
50
100 km

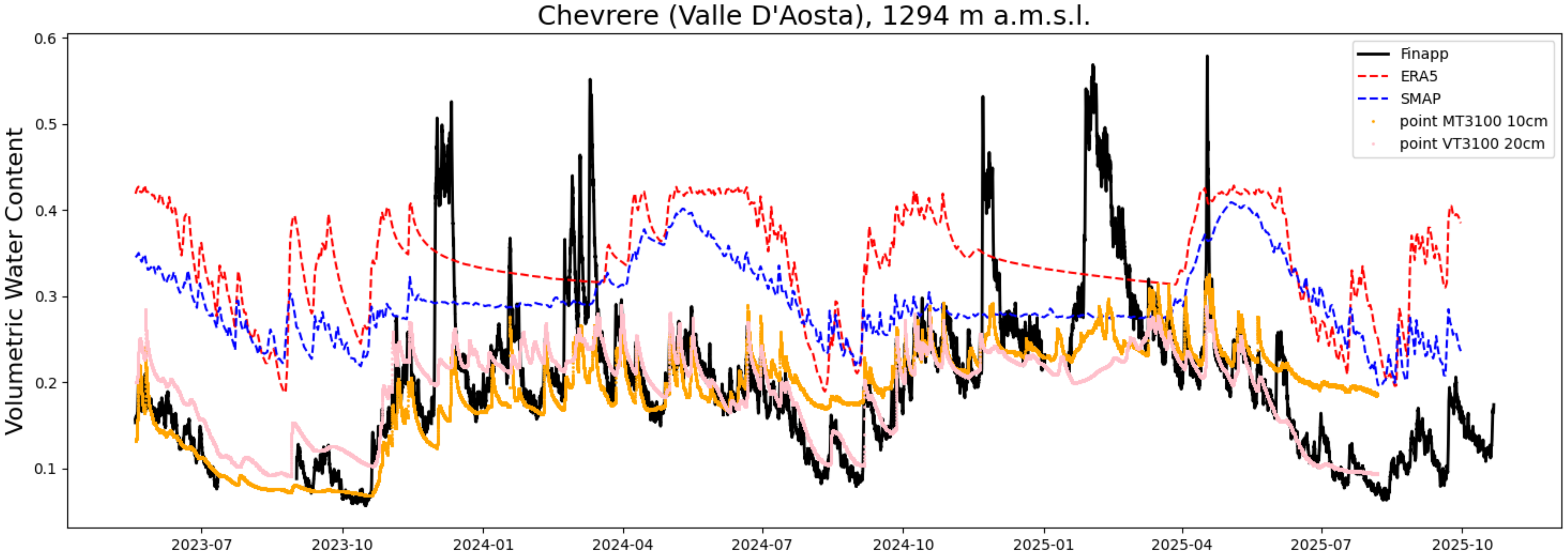
Grassland sites





Forest sites

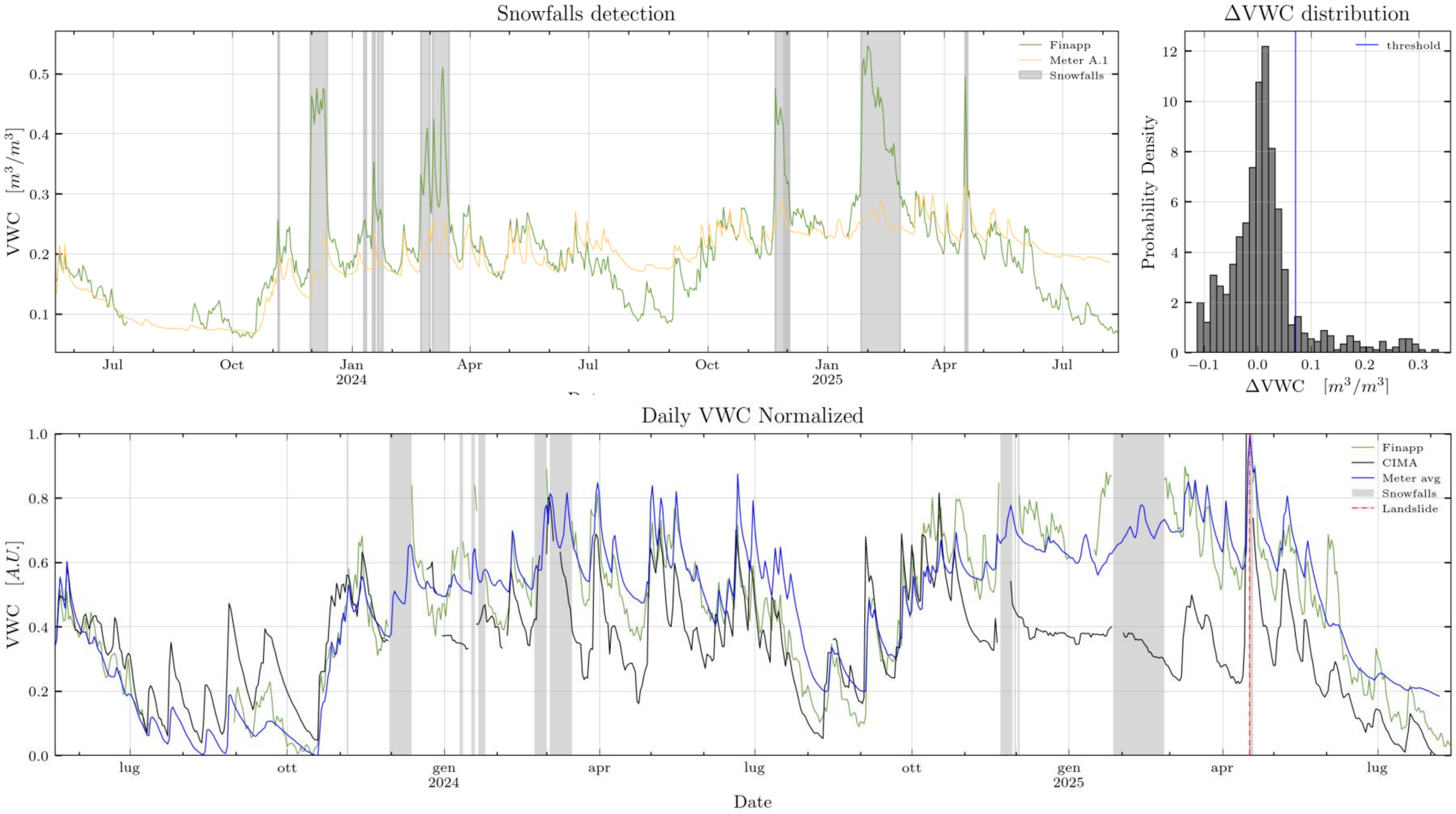




Overestimation by both remote sensing products is observed.

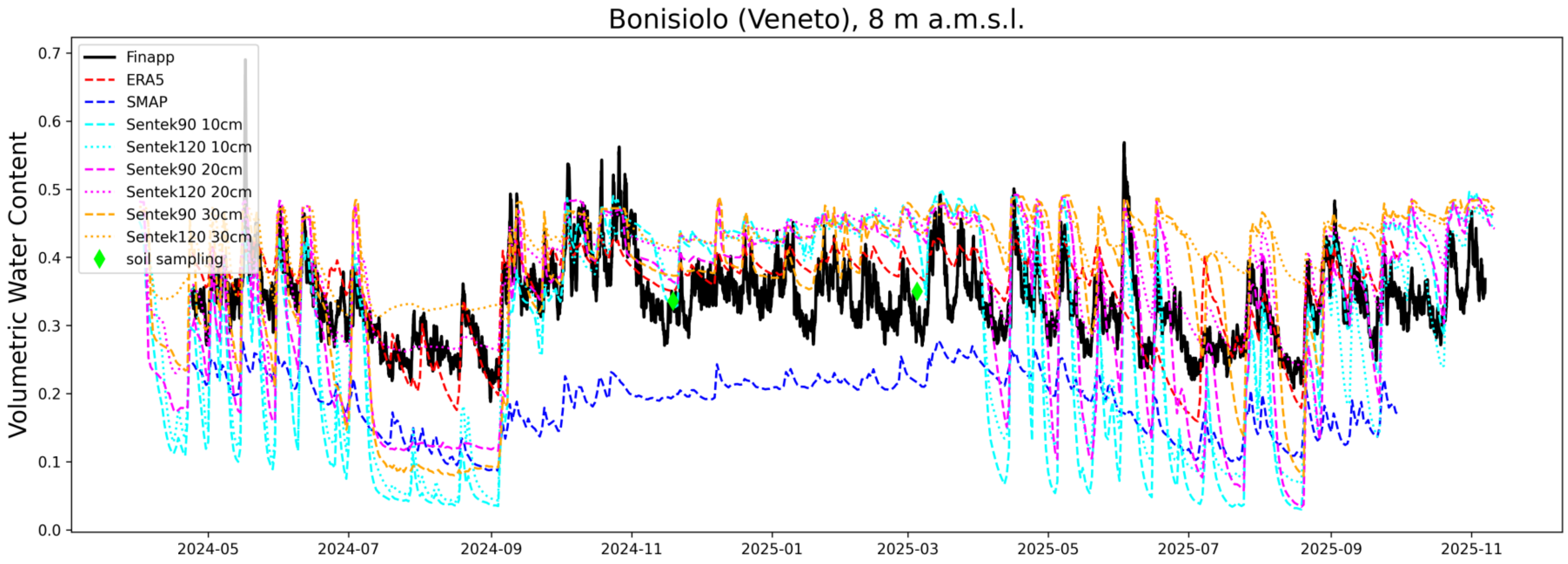
Snowfall detection

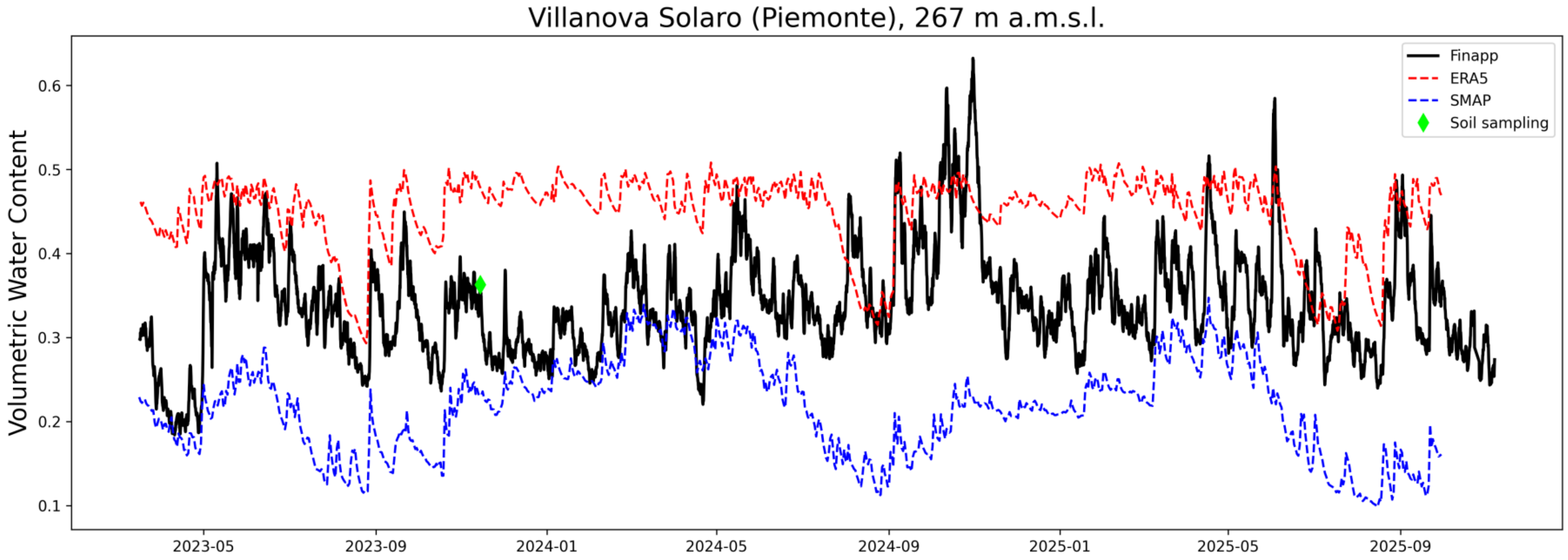
An example of how the point measurement can help in the interpretation of the CRNS measurement. A cut on the distribution of the difference between the measurements successfully identifies the snowfalls.



(Presented in the poster *«Introduzione del Cosmic Ray Neutron Sensing nel monitoraggio di un pendio con instabilità»* at the «Giornate Italiane dell'Idrologia», Sept. 8-10, 2025, Bari, Italy)

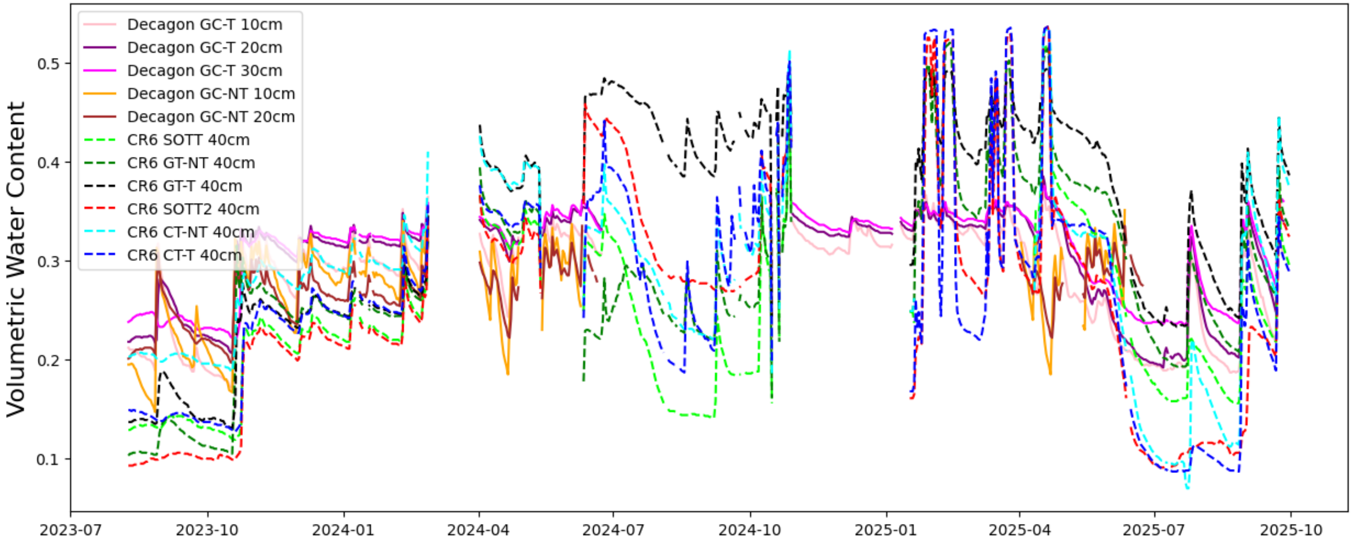
Crop sites

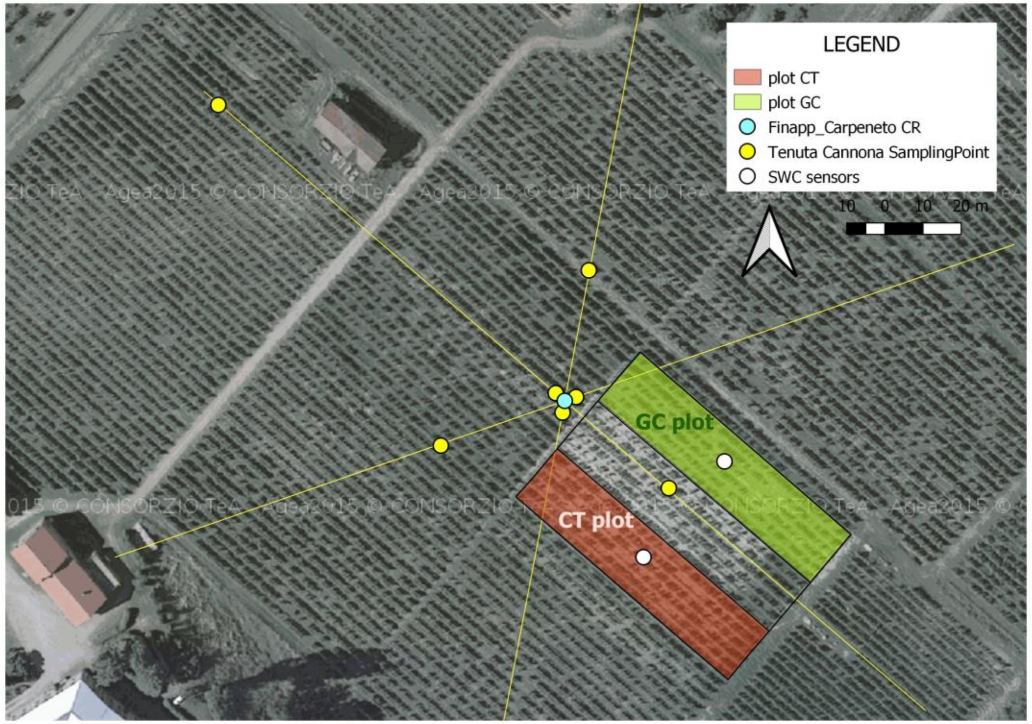


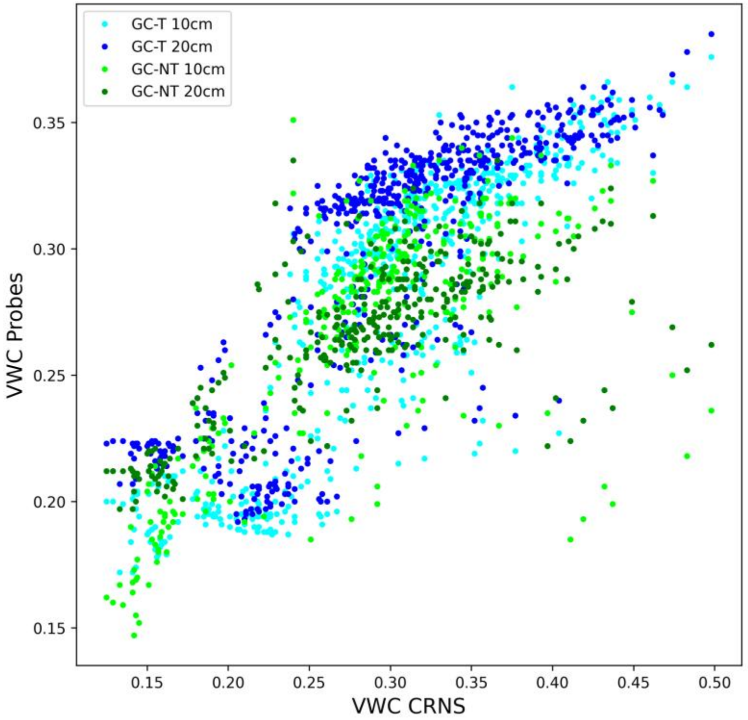


Large offset between the two remote sensing products.

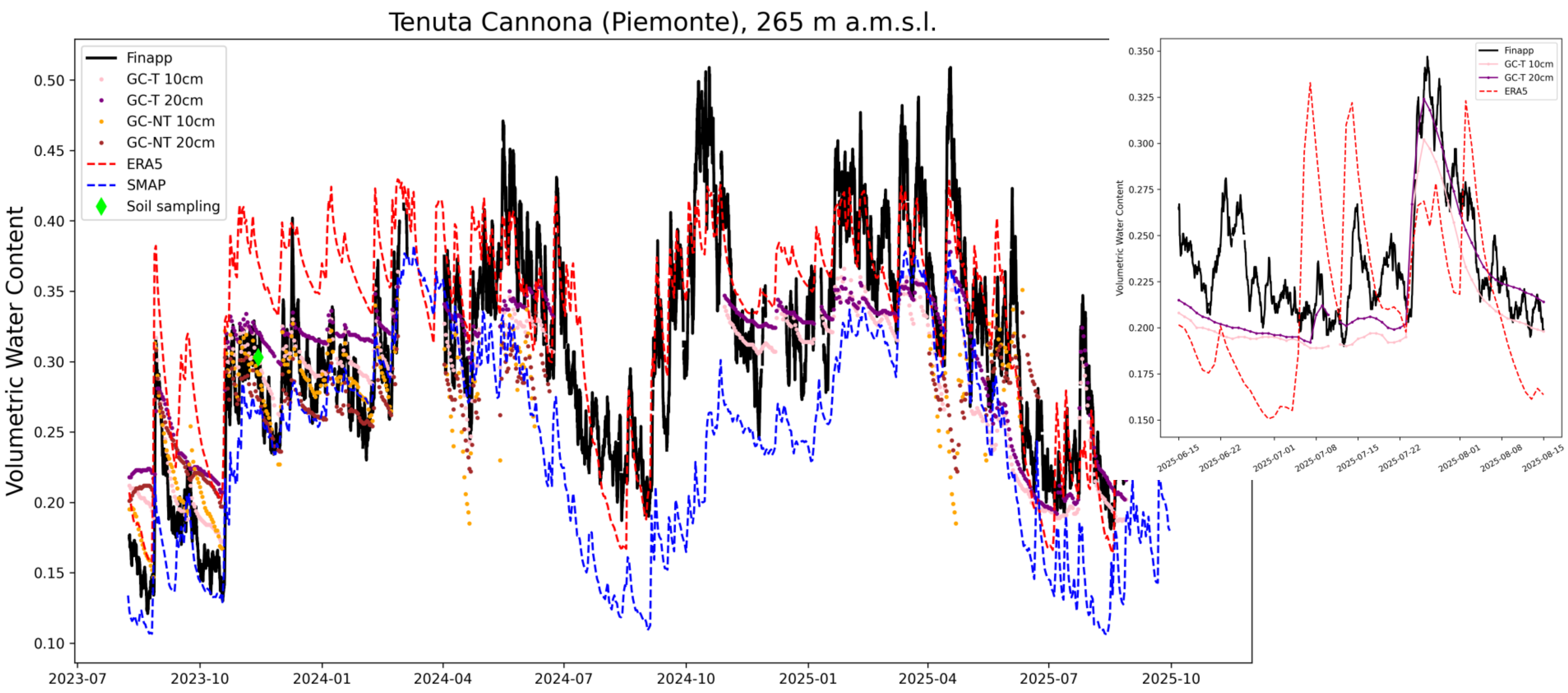
Vineyard (Tenuta Cannona)







Vineyard (Tenuta Cannona)



- According to the correlation analysis, CRNS matches better the GC-NT, which in fact represents the prevalent condition.
- CRNS is better correlated with superficial measurements
- Rainfalls of less than 10 mm during summer (dry starting condition) are not detected by point probes but they are detected by CRNS and remote sensing.
- Point probes are very affected by the soil use and treatment while CRNS maintain a coherent representation of the overall conditions.

Conclusions and perspectives

- Generally consistent dynamics by the different methods, but absolute values typically mismatch.
- What is the origin of the sistematic discrepancies of remote sensing products? Can CRNS help?
- What further knowledge can we gain by combining the information from CRNS and point probes? (example: revealing snowfalls)
- How does the agricultural management affect the different measurements? (grass vs tilage; induced bulk density variations; different transpiration and infiltration)
- Do we observe more coherency in natural environments?

Thanks for your attention!

Poster C51D-0374 (ongoing in Poster Hall)
«Measuring Snow Water Equivalent (SWE) at Multiple Scales by Cosmic Ray Probes »

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