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## Background

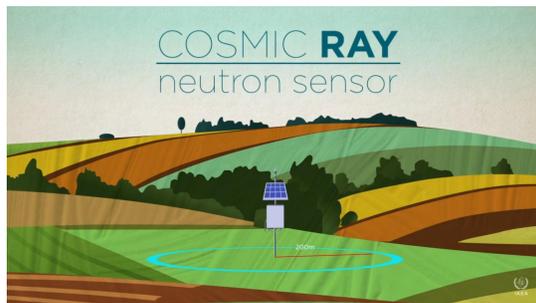
- **New observation systems** are developed, tested, and implemented at **high-level experimental test sites**.
- These observatories have boosted research and collaborations providing the basis for process understanding and model improvements.
- **In contrast, national and more operational ground monitoring networks** are still largely based on **traditional instruments**. Moreover, the different networks and the data are not always well integrated, even at the regional level.
- For these reasons, **the capability** to monitor the main components of the hydrological cycle over large areas **is still limited** and should be improved to provide better management of the water resources and for environmental protections.

**Objective:** by using soil moisture (and snow water equivalent) monitoring as examples, in this contribution we present and discuss challenges, results and opportunities in upgrading national weather stations and improving the service provided by the public environmental agencies by means of cosmic-ray neutron sensing (CRNS).

### 1. Identify gaps and new data production (CRNS ~ 2005)

Cosmic ray neutron sensing (CRNS) has been proposed as a new ground non-invasive approach for intermediate scale observation of land surface hydrogen pools.

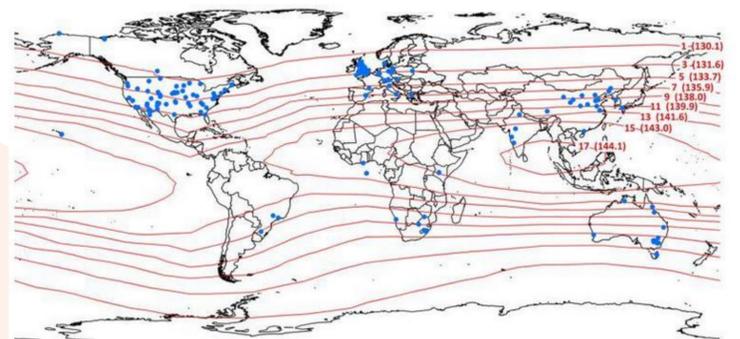
Originally developed for soil moisture measurements, it has also shown promising applications for snow, biomass and canopy interception [1].



<https://www.iaea.org/newscenter/multimedia/videos/cosmic-ray-neutron-sensor-crns-from-cosmic-rays-to-soil-moisture>

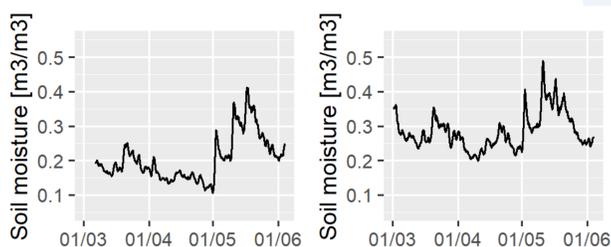
### 2. Testing and spread (~ 2018)

The use of CRNS have seen a strong spread over research groups. Several networks have been established [2]. The use outside research and academy remained limited.



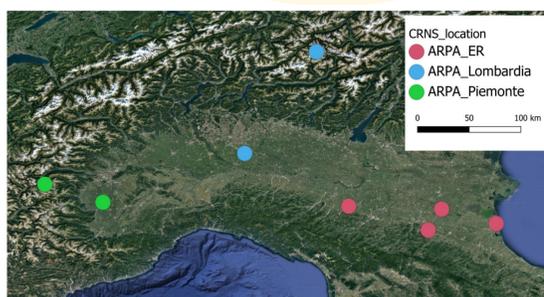
### 5. Applications (> 2023)

From drought monitoring to flood predictions, remote sensing and land surface model assessments and data assimilation.



### 4. From research towards a CRNS soil moisture network in Italy (~ 2023)

After a first engagement in a testing phase, some Italian environmental protection agencies are now establishing a CRNS network for long-term soil moisture (and snow) monitoring. Collaboration has been established to support calibration, data processing, data sharing, optimization of the installations.



### 3. New instruments and standardized data processing tools (~ 2022 - 2025)

The measurements were generally performed based on moderated proportional counters filled with Helium-3 or Boron. New instruments are nowadays on the market based on different technologies. User friendly toolkits are also proposed.

The **SoMMet EU-project** [3] (<https://www.sommet-project.eu/home>) aims to establish standard and traceable measurements over different soil moisture methods and scales.

## Conclusions and outlook

- **A long journey** from the identification to the implementation (e.g., twenty years). Need of long-term vision. Difficult when short projects
- **Many actors**. Key to identify **expertise** and roles: Data production -> data base management and integration -> data analytics
- **Collaborations and interdisciplinarity** initially take time but later **help to speed up** the process

## References and acknowledgment

- [1] Zreda et al. "Measuring Soil Moisture Content Non-Invasively at Intermediate Spatial Scale Using Cosmic-Ray Neutrons." GRL, 2008. <https://doi.org/10.1029/2008GL035655>.
- [2] Andreasen et al. "Status and Perspectives on the Cosmic-Ray Neutron Method for Soil Moisture Estimation and Other Environmental Science Applications." VZI 2017. <https://doi.org/10.2136/vzi2017.04.0086>.
- [3] The project 21GRD08 SoMMet has received funding from the European Partnership on Metrology, co-financed by the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.
- [4] The research activities are also partially conducted within the CRP IAEA project D12014 Enhancing agricultural resilience and water security using Cosmic-Ray Neutron Sensor.