Measurements, Modelling, Data Assimilation and Uncertainty for Hydrogeophysical characterization of the Earth's Critical Zone

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The Earth's Critical Zone (CZ) is the thin outer veneer of our planet from the top of the tree canopy to the bottom of our drinking water aquifers. The CZ supports almost all human activity, is experiencing ever-increasing pressure from growth in human population and wealth. Understanding, predicting and managing intensification of land use and associated economic services, while mitigating and adapting to rapid climate change and biodiversity decline, is now one of the most pressing societal challenges of the 21st century. This project aims at developing, testing and validating an integrated approach solidly based onto non-invasive geophysical techniques, for the monitoring and modeling of the CZ. Particular attention will be devoted to the soil-plant-atmosphere (SPA) interactions, with particular attention to the spatial and temporal distribution of soil moisture as an effect of precipitation, irrigation, redistribution, infiltration and root uptake ("green water"). The SPA interactions play a critical role in the exchanges of mass and energy, that in turn control a number of environmental processes in the CZ, including those affecting and mitigating climatic changes (CC). Also, of the utmost importance is the understanding of the relevant processes taking place in agricultural practice, in order to optimize irrigation and plant resilience in face of expected climatic changes and growing population demands ("more crop per drop"). In spite of these challenges, our understanding of the complex CZ and SPA interactions is often limited by the lack of spatially extensive and time intensive data, particularly regarding the subsoil components, including root activities, and their changing states. Common point-based methods do not allow the investigation of spatial distribution of state variables. Remote sensing generally penetrates the subsoil only by a few centimeters and their view of the subsurface is hindered by vegetation itself. Ground-based, non-invasive (geophysical) techniques such as Electrical Resistivity Tomography (ERT), Electromagnetic Induction (EMI) and Ground-Penetrating Radar (GPR) can be applied at different scales to image static and dynamic characteristics of the subsoil, in response of hydrological stresses. Larger scale measurements, such as Eddy Correlation towers and Cosmic Ray probes, complement the suite of available tools. An inordinate quantity of field data is often available at well equipped field sites, but the integration of all such data into a coherent conceptual model of the CZ is still in its infancy.

This project aims at combining novel measurement approaches to advanced SPA modeling via advanced Data Assimilation techniques. Specifically, the project aims at:

- analyzing the specific capability of each measurement technique at studying the small-scale dynamics of moisture content under different site conditions;

- testing and validating the capabilities of small-scale hydro-geophysics in monitoring eco-hydrological processes at the scale of interest for SPA interaction for CZ characterization, with specific attention to their spatial scale investigation capabilities, and their repeatability over time;
- complementing the data concerning the dynamic soil moisture distribution with mass and energy flux data from sap flow, stem flow and eddy correlation measurements, in order to feed this essential information into mechanistic models that are, primarily, based upon mass balance considerations;
- coupling the spatially extensive and time intensive data obtained from traditional and innovative minimally invasive techniques with mechanistic models representing the soil moisture dynamics and root water uptake (RWU), whole plant transpiration, and leaf-level photosynthesis, using data assimilation (DA) techniques, with the aim of producing spatially heterogenous models of soil hydraulic properties to be used in predictive models, such as those needed in estimating soil-plant-atmosphere interactions.

This integrated approach will be applied to a number of sites where existing traditional and innovative instrumentation has already been partly put in place as part of funded projects and existing established collaborations at local, national and international levels. The project builds upon experience and expertise coming from a multidisciplinary set of researchers.

This project will benefit from the collaboration with active research groups at the University of Florence (Prof. Daniele Penna), the University of Naples Federico II (Prof. Nunzio Romano), the University of Lausanne (Prof. Paolo Benettin) and CNR-IGG, active at a number of field sites in Tuscany, Campania, Val d'Aosta and abroad, ranging from agricultural land to arid environments, and from mountain landscapes to Mediterranean climate. Funding will be made available by the proponents from existing projects (GROWING, WASA, ESR, GLOBAQUA, ECZ-Dry).