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Editorial: Critical zone geophysics

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Editorial on the Research Topic
Critical zone geophysics

The critical zone (CZ) is the outermost layer of our planet where life, air, water and rocks interact. The CZ hosts a wide variety of hydrological, geochemical and biological processes that occur across multiple scales, thereby shaping landscapes, sustaining ecosystems and regulating resource availability. The deepest part of the CZ, consisting of the soil continuum, regolith and fractured bedrock, plays a major role in its overall functioning as it controls water flow partitioning and storage, soil formation and nutrient production and availability. However, difficulty accessing information about the CZ architecture, properties, and dynamics at depths greater than several meters limits our understanding of how the CZ works. In this Research Topic, seven studies demonstrate that geophysical methods can help to overcome these difficulties by measuring, in a non-invasive way and at different scales, several physical parameters that are linked to variations in the properties and processes of the CZ at depth.

First, the main water inflow of the CZ comes from meteoric water (precipitation or snow accumulation) that infiltrates through the atmosphere-plant-soil continuum. Quantifying these fluxes requires an understanding of vegetal structure and dynamics to quantify and delineate water exchange behavior. To address this topic, Mary et al. presented a Bayesian approach using electrical geophysical monitoring to model root water uptake. The authors rely on developments in agro-geophysics that allow for imagery of root systems and water variations in the soil to improve the hydrological root model parametrization. Their work demonstrates the ability of electrical monitoring to localize water storage variation in root systems and quantify vegetation drawdown of these water sources. The latter is constrained by vegetation growth dynamics. To better understand this, Harmon et al. used electrical monitoring of a tree trunk to follow the dynamics of sap flow within it. They demonstrate the influence of storms and droughts on plant stomatal hydraulic strategies and then in its transpiration. These two studies highlight the possibility of constraining water flows in the atmosphere-plant-soil continuum and thus better quantify recharge into the deep CZ.

Below the soil, the circulation of recharge is controlled by the structure and properties of the geological horizons. In general, the CZ is conceptualized as layers of soil, saprolite, fractured bedrock and less weathered bedrock. Nielson et al. probes deeper into the CZ structure using seismic refraction tomography to characterize its different layers and their spatial variation. The authors show that in snow-dominated montane catchments, deeper snow accumulation leads to deeper weathering near the crest. The resulting thickness of the weathering zone decreases down drainage. In the meantime, Flinchum et al. went beyond CZ structure imagery by exploring the potential of P-wave velocities to estimate ground properties and heterogeneities across scales. They demonstrate that seismic refraction can quantify the general location of boundaries defined by changes in porosity in the CZ at the scale of the dominant wavelength (defined by the velocity and frequency of the source). These two studies highlight the utility of geophysical methods, notably seismic, to understand CZ structure and link it with climatological, geological and morphological factors.

After characterizing the CZ structure, it is crucial to quantify water storage capacity and monitor its dynamic. To do so, de Pasquale et al. combine electromagnetic soundings with hydrogeological, geological and geomorphological investigations. The authors demonstrate the value of geophysical imaging to identify groundwater reservoirs, define their geometry and quantify their contribution. Another approach is to use gravity methods such as Chaffaut et al., who combine a precise and continuous *in-situ* gravity monitoring with a spatial acquisition on 16 stations. Their approach provides high temporal monitoring of water storage at the catchment scale, which is downscaled using 16 time lapse measurements. Based on this, they are able to quantify the spatial variations of temporal water storage dynamics highlighting the poorly understood groundwater behavior. They demonstrate how the gravity method could be an asset for constraining process-based groundwater models. Both approaches illustrate how reliable geophysics is for understanding water temporal dynamics and spatially constrain groundwater flows within the CZ.

These groundwater flows typically end up in the river of the watershed. The exchange between the aquifer and the river takes place within the hyporheic zone, within which many biogeochemical processes take place. While water storage quantification helps to estimate water balance, the spatial complexity of the hyporheic zone requires an accurate characterization to understand surface- and groundwater exchanges and associated biogeochemical reactions. To this end, Cucchi et al. have developed a monitoring instrument combining thermal and pressure measurements to quantify water flows in the hyporheic zone and estimate its hydrodynamic properties. The authors demonstrate that geophysical monitoring can track both recharge and drainage of the river to improve our understanding of exchanges between the surface and the subsurface. In the future, such geophysical approaches combined with biogeochemical analysis will help improving our understanding of biological processes occurring in the hyporheic zone.

In conclusion, through the wide variety of studies proposed by the contributors of this Research Topic, it has been possible to show the strength of geophysical methods for understanding a wide range of processes taking place within the CZ from the atmosphere-plant-soil continuum to the bottom of aquifers. Each geophysical methods provide integrated measurements of a specific physical properties (e.g., velocity, resistivity, gravity) with resolution limits associated to the acquisition parameters (e.g., frequency, sensors spacing). With the right acquisition set-up, the geophysical monitoring will measure indirect parameters at the spatial and temporal scale of interest. These integrated measurements limit the bias from small-scale heterogeneities. Then, the combination of different physical principles allows a better understanding of the structure of the CZ, as well as its spatial and temporal dynamics. Furthermore, as subsurface physical properties are impacted by several processes, geophysics give the opportunity to follow the interaction of several processes. While the studies published in this Research Topic focus on the interaction of the water cycle with the CZ, a major challenge today lies in combining this water cycle dynamic with geochemical and biological processes to go beyond our current understanding of pluridisciplinary CZ processes. In the future, geophysical monitoring will increasingly enable the simultaneous monitoring of geochemical, hydrological, and biological processes to better constrain the complex interactions between major compartments of the CZ, thereby gaining unprecedented insight into CZ dynamics across spatiotemporal scales.

Author contributions

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Conflict of interest

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