Soil-plant-atmosphere interactions: monitoring using geophysical methods and consequences for atmospheric predictions.

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Weather and climate predictions are among the hottest scientific topics of the past couple of decades. In many cases, the most important use of such predictions is to assess what will happen to the surface, where we live. On the other hand, the lower boundary conditions of meteorological and/or climatic models are usually described just by simplified models of mass (especially water and carbon) and energy (sensible and latent heat) fluxes. This project wants to address one fundamental issue at the heart of these predictive models: the current description of the surface boundary conditions is still primitive, and even though they have evolved in the past few years, they cannot yet represent the complexity of the surface and subsurface soil-water-vegetation processes that actually take place. In particular, these boundary conditions are designed to mimic the immediate response of the very shallow soil (down to about 1 m), and of the vegetation resting upon it, to the atmospheric forcing conditions. No mention is made of the underlying deep soil dynamics, and no link is made between the plant evapotranspiration and the consequent redistribution of moisture content in the soil, that is simulated at best as a thin 1D vertical system. While this rough description of the atmosphere-soil-water-vegetation interactions may be acceptable for Numerical Weather Prediction (NWP) [CL16] at low spatial resolution, this is not so for the very pressing topic of climatic prediction in terms of Global and Regional Climate models (GCMs and RCMs), from seasonal to multi-decadal time scales [WP05]. In addition, recent evidence [HA24] shows that the adoption of finer spatial resolution atmospheric models (at about 2 km resolution) has a double effect: (a) on one hand they make possible to simulate atmospheric convection (thus these models are named “convection resolving models” or CRMs), but (b) when using CRMs it is absolutely necessary to correctly capture land surface feedbacks, which play an important role in weather and climate projections.

Current boundary conditions are generally described by Land Surface Models (LSMs) [BO21], already evidencing a certain lack of perspective with respect to the existence of a subsurface that has multifaceted processes and roles. Two relatively recent concepts dealing with this planetary interface are particularly useful in providing a new comprehensive view of these processes: (a) the Soil–Plant–Atmosphere Continuum (SPAC), first introduced by John Philip [PH66], allows the description of this interface in the framework of continuum physics, with a specific emphasis on soil-plant interactions, mainly through the root zone; (b) the Critical Zone (CZ), first defined by the National Research Council [NRC1] as “the layer between the bottom of the surface aquifer and the top of vegetation canopy” [GH15].

Objectives

The project has the overarching goal of addressing the fundamental question of whether, and to what extent, an adequate description of the land-atmosphere boundary conditions, in their spatial variability, together with a proper account of the soil-plant interactions, and of the water (and thus energy) lateral redistribution in the subsurface can change significantly the capability of atmospheric models to predict short- and long-term phenomena (Fig.1). As a consequence, such a new paradigm can improve the capabilities of hydrological models to predict the responses in terms of, e.g., floods and droughts.

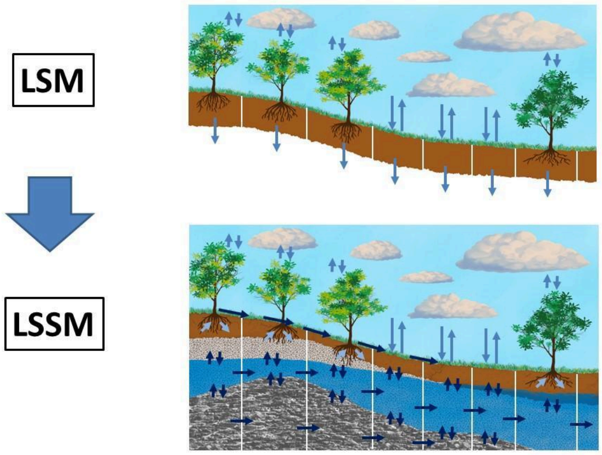

Figure 1: conceptualization of the components of the new Land Surface and Subsurface Models (LSSMs) as compared to those of existing LSMs. Note the relationship with the SPAC and CZ concepts, and the strong importance of plant-soil fluxes and lateral fluxes between cells (both on the surface and at depth), all aspects totally neglected in current LSMs.

In order to achieve the goals above, a fundamental building stone is a proper characterization and monitoring of the near-subsurface. As of today, our understanding of the complex CZ and SPAC 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.

The main area of research covered by the potential PhD student will be the combination of novel measurement approaches to advanced SPAC 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;

- complementing the data concerning the dynamic soil moisture distribution with mass and energy flux data from sap flow, stem flow and eddy correlation measurements;

- 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.

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