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Inverse Modeling in Subsurface Hydrology

Abstract

Inverse modeling is applied when mathematical models requires the inference of parameters which are difficult to measure directly. Examples can be found in astronomy, medicine, meteorology and hydrology, to mention a few. The major advantage of inverse modeling is that it allows data fusion in order to find the model representation which is most consistent with the observations. At the catchment scale, the progress in understanding hydrological processes relies on making the best possible use of advanced models and the large amounts of data that are now being made available. For example, processes at the interface between the atmosphere and the land surface control the partitioning of rainfall into infiltration and runoff and the redistribution of water between the surface, soil, underlying aquifers, and streams. Understanding these exchanges is extremely important for agriculture (irrigation planning and vegetation growth), natural hazards prevention (floods, erosion, landslides), and for water quality management (point and non point source pollutants in catchment and stream waters). Hydrology has been a science characterized by scarceness of data. Most of the fluxes in the hydrologic cycle are difficult to measure directly, especially over large areas. Usually, hydrologic variables are measured only at few locations or times. This scenario may change dramatically in the future with the increasing availability of remote sensing data and automated ground-based sensors. However, most of these data are only indirectly related to the fluxes and variables of most interest in hydrologic applications. Inverse modeling is applied with increasing frequency in hydrology and it is beginning to influence the way hydrologists think about data collection and modeling. A first contribution concerns with the estimation of the hydraulic parameters in the vadose zone by means of infiltration experiments monitored through Ground Penetrating Radar (GPR). The focus is on the influence of ponding conditions and different sampling strategies on the accuracy with which hydraulic parameter can be inferred from GPR data.

Moving to the catchment scale time series analysis has been applied to hydrological and geochemical signals recorded at two karst springs, located in the Dolomiti del Brenta region near Trento, Italy, in order to infer how karst catchments work internally to generate runoff. Runoff generation assumes different characteristics depending on the meteorological forcing and seasonal climatic changes and there is clearly a link between the multiplicity of time scales observed in the runoff signal and the hydraulic property variations of the underlying aquifer feeding the springs. However, this link is non-linear because of both the selective effect of the hydrological input on the activated scales and the dependence of the travel time from the hydraulic head (pipeflow), which depends on pre-event soil water content. Field data including precipitation, spring flow and electric conductivity of the spring water have been analyzed. All the signals have shown the signature of multifractality but with different degree of intermittency and non-stationarity. In particular, precipitation and spring flow are shown to have nearly the same degree of non-stationarity and intermittency, while electric conductivity, which mimics the travel time distribution of water in the karst system, is less intermittent and smoother than both

spring flow and precipitations. An important result is that the probability distribution of travel times is inconsistent with the advection dispersion equation, while it supports the anomalous transport model.

Modeling such non-linearity is the challenging task of the second part of this work. The discussion is currently focused on pros and cons of distributed, physically based models (based on theories of small scale processes requiring large data sets at a large computational burden) versus lumped conceptual models (simplified model structure often lacking of physical basis, faster in set-up and computational times, more modest in terms of input data). One of the main disadvantages of physically based models is the large amount of data they require relative to lumped models. Thus, parameterization and validation become major tasks. Despite the great effort required to validate and run such physically based models, simulated results often provide only slightly better or even worse correspondence with measured internal quantities than the lumped models. Established the need of simple conceptual models, the travel time approach has been applied to model the complexity of karst environments and small alpine catchments. The travel time approach is a very promising approach for modelling runoff generation at the catchment scale. However, several aspects need further analysis, such as the identification of the most convenient residence time pdf for the sub-elements in which the catchment is divided and the non-linearity in the rainfall-runoff transformation, to mention a few. Non-linearity in the rainfall-runoff transformation, which is typically addressed by using the concept of "effective" precipitation, is the main objective that has been pursued in this work developing a continuous, dynamic, model for the soil response with the total rainfall as input. Furthermore, the travel time pdf has been derived from spectral analysis conducted on the hydrological signals registered at the karst spring. The resulting model, supplemented with a simplified snowmelt and snowpack model as well as with an evapotranspiration model, performed well both in calibration and in validation.