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A new index to quantify hysteresis at the runoff event timescale

Giulia Zuecco (1), Daniele Penna (2), Ilja van Meerveld (3), and Marco Borga (1)

(1) Department of Land, Environment, Agriculture and Forestry, University of Padova, Legnaro (PD), Italy (giulia.zuecco@unipd.it), (2) Faculty of Science and Technology, Free University of Bozen-Bolzano, Bolzano, Italy, (3) Department of Geography, University of Zurich, Zurich, Switzerland

Hysteresis is a non-linear loop-like behavior that is common in natural systems. Hysteresis is common in the relation between streamflow and a number of other hydrologic variables, e.g., groundwater levels, soil moisture, extent of the saturated area, and sediment and solute concentrations. Analysis of these hysteretic patterns at the event time scale can lead to a better understanding of the processes underlying the catchment hydrological response. Hysteretic patterns can also be used for model calibration and testing.
Several indexes have been developed to analyze hysteresis and quantify the direction and the extent of the loops, particularly to determine hysteresis in the relation between sediment concentrations and runoff. However, they typically suffer from a degree of subjectivity, do not take into account complex hysteretic patterns and are therefore not always applicable to describe other hysteretic relations as well. Therefore, we present a new versatile index for the quantification of a wide range hysteretic loops between hydrological variables at the runoff event timescale and test the sensitivity of the index to the temporal resolution of the measurement data and measurement errors.
The conceptual development of the new hysteresis index is based on i) a normalization to compare hysteretic loops at different space- and timescales, and ii) the computation of the slopes of segments connecting the initial state to observations of the independent variable. The index provides information on the direction, the extent and the shape of the hysteretic loops. The index was tested with hydrological data from three experimental catchments in Northern Italy. Hysteretic relations between streamflow (the independent variable) and four different dependent variables (soil moisture, groundwater level, isotopic composition of stream water and electrical conductivity of stream water) were correctly identified and quantified by the index. The objective quantification of hysteresis by the index allowed for the robust classification of hysteresis in datasets and thus to determine differences in hydrological responses for different events. The index also captured the switch in the direction of the hysteretic relation between soil moisture and streamflow with changes in event size and antecedent wetness conditions well. Finally, the sensitivity analyses showed that the index was little affected by the temporal resolution of the measurements and random errors in the input data.

Keywords: hysteresis index; hysteretic loops; streamflow; soil moisture; seasonal dynamics; sensitivity analysis