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Fuzzy-logic based ensemble smoother data assimilation frameworks for improving the informational value of the assimilated data

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Remote sensing data has been increasingly used to get improved estimates of spatially distributed hydrological variables. Although the relative informational value of time-series observations varies in response to multiple factors, the commonly used ensemble based smoothing schemes assume crisp and equal informational value for all observations of the assimilated data. The particle batch smoother (Pbs) is one of these schemes that has been gaining interest as a data assimilation (DA) scheme in hydrological models due to its distribution free likelihood and its capability to estimate the state vector directly at a relatively low computational cost. However, one of the main challenges in using Pbs and other Bayesian-based DA schemes is, that most of the weights are assigned to one or very few ensemble members and this may lead to degeneration of the statistical information in the ensembles. Here we consider an alternative approach that ensures fair distribution of weights among ensemble members based on the limits of acceptability concept (LoA). In this study, LoA was adopted as a DA scheme by introducing a methodology for relaxing the strict requirement of its original formulation as a rejectionist framework. A fuzzy coefficient was also introduced in both ensemble-based DA schemes to take into account for the variability in informational value of the assimilated observations.
The fuzzy-logic based DA schemes were applied to a case study focused on the assimilation of remote sensing fractional snow cover area (fSCA) into a hydrological model. Timing of the more informative period was assumed to vary both spatially and temporally in response to various climatic and physiographic factors. Accordingly, the assimilation period was partitioned into three timing windows based on the critical points in the time axis where the mean snow cover changes and where the melt-out period starts. An automatic detection approach was used to locate these critical points. The parametric (likelihood-based) and non-parametric change point detection schemes employed to locate the change point in each grid cell and year yielded reasonable results. Similarly, the DA scheme based on LoA has yielded an encouraging result. An improved estimate of SWE was also obtained in most of the analysis years as a result of introducing the fuzzy coefficients in both DA schemes. The most significant improvement was obtained in the correlation coefficient between the predicted and observed SWE values; with an increase by 8% and 16% after introducing the fuzzy coefficient in Pbs and LoA, respectively. Results from this study suggest that, the concept of variable informational value of the assimilated observations is consistent with the notion that many of the variables that we usually consider to be crisp quantity and deterministic are actually fuzzy that carry considerable amount of uncertainty.