Geophysical Research Abstracts
Vol. 13, EGU2011-2647, 2011
EGU General Assembly 2011

Many-Objective Groundwater Monitoring Network Design using Bias-Aware Ensemble Kalman Filtering, Evolutionary Optimization, and Visual Analytics

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Long-term groundwater monitoring (LTM) design has long been recognized to have many conflicting objectives within a severely challenging planning problem. Our research efforts have focused on demonstrating how bias-aware Ensemble Kalman Filtering (EnKF), "many-objective" search, and visualization can be combined to facilitate discovery and negotiation in the LTM design process. Our use of the terms discovery and negotiation is motivated by the potential of "many objective" solution sets to identify alternatives that capture a broad suite of system behaviors relevant to both modeled and unmodeled objectives, helping decision makers to "discover" system dependencies and/or tradeoffs and exploit this information in the negotiated selection of a solution. This work advances beyond prior groundwater monitoring design studies by enhancing many-objective solution tools and making groundwater transport forecasts more robust to nonlinearities while also accounting for measurement uncertainties and dynamic, spatiotemporally correlated model structure errors. Designing LTM networks for contaminated groundwater is a challenging problem that has long been recognized to suffer from the "curse of dimensionality". LTM design problems have discrete decision spaces that grow exponentially as the different types of measurements, their locations, and sampling rates are considered. The scaling challenges of the LTM network design problem have been discussed in the water resources literature for more than 30 years. Our work seeks to overcome this scaling constraint by developing a new class of multiobjective solution tools. We are developing Hierarchical Bayesian search methods that can learn and exploit the spatiotemporal structural relationships between monitoring decision variables. For example, the search algorithm should distinguish the information provided by samples along a plume's evolving boundaries versus samples in its source area. In combination, the forecasting, search, and visualization tools developed in this research define the ASSIST (Adaptive Strategies for Sampling in Space and Time) monitoring framework. The ASSIST framework has a strong potential to innovate our characterization, prediction, and management of groundwater systems.