Evaluating potentials and corresponding risks of deficit irrigation sytems: comparison of two stochastic optimization strategies

Sebastian Kloss, Niels Schütze, and Michael de Paly

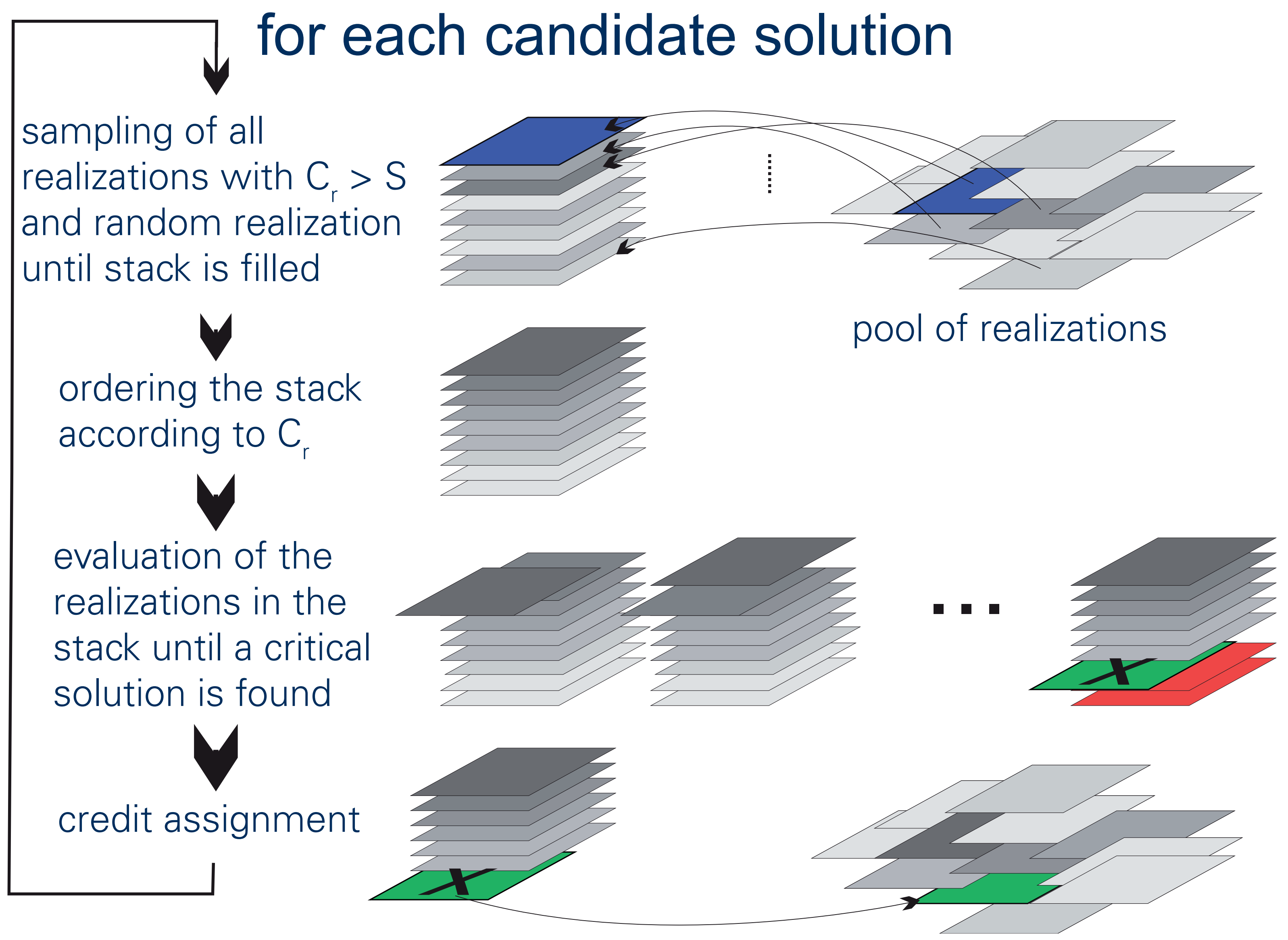
Institute of Hydrology and Meteorology, Dresden University of Technology, Germany

1. Introduction

The scarcity of water constitutes a main drawback within agricultural production and effective adaption measures are of great importance to face climate variability under climate change for ensuring food security. Besides improving irrigation techniques, the problem of solving intra-seasonal irrigation scheduling under limited seasonal water supply and different sources of uncertainty (e.g. climate, soil conditions, and management) is of utmost importance.

To treat this uncertainty within a simulation optimization framework for irrigation management it is necessary to formulate a tractable probabilistic framework that avoids the considerable computational effort of Monte Carlo simulations. This applies particularly for ensuring food security since quantiles above 90% are of interest, which require large evaluation sets for convergence. The following approach demonstrates the efficiency of a stack-ordering technique for generating high productive irrigation schedules that are based on a statistically appropriate subset of realizations and a reliable optimal management. The optimization aims at evaluating the minimum water demand for a given yield and corresponding reliability in deficit irrigation strategies. The procedure is combined with an evolutionary optimization algorithm.

An example from an agricultural area in the Al-Batinah in Sultanate of Oman is given that compares the performance of the stack-ordering technique to an ordinary Monte Carlo simulation.



for each candidate solution

sampling of all realizations with $C_r > S$ and random realization until stack is filled

ordering the stack according to C_r

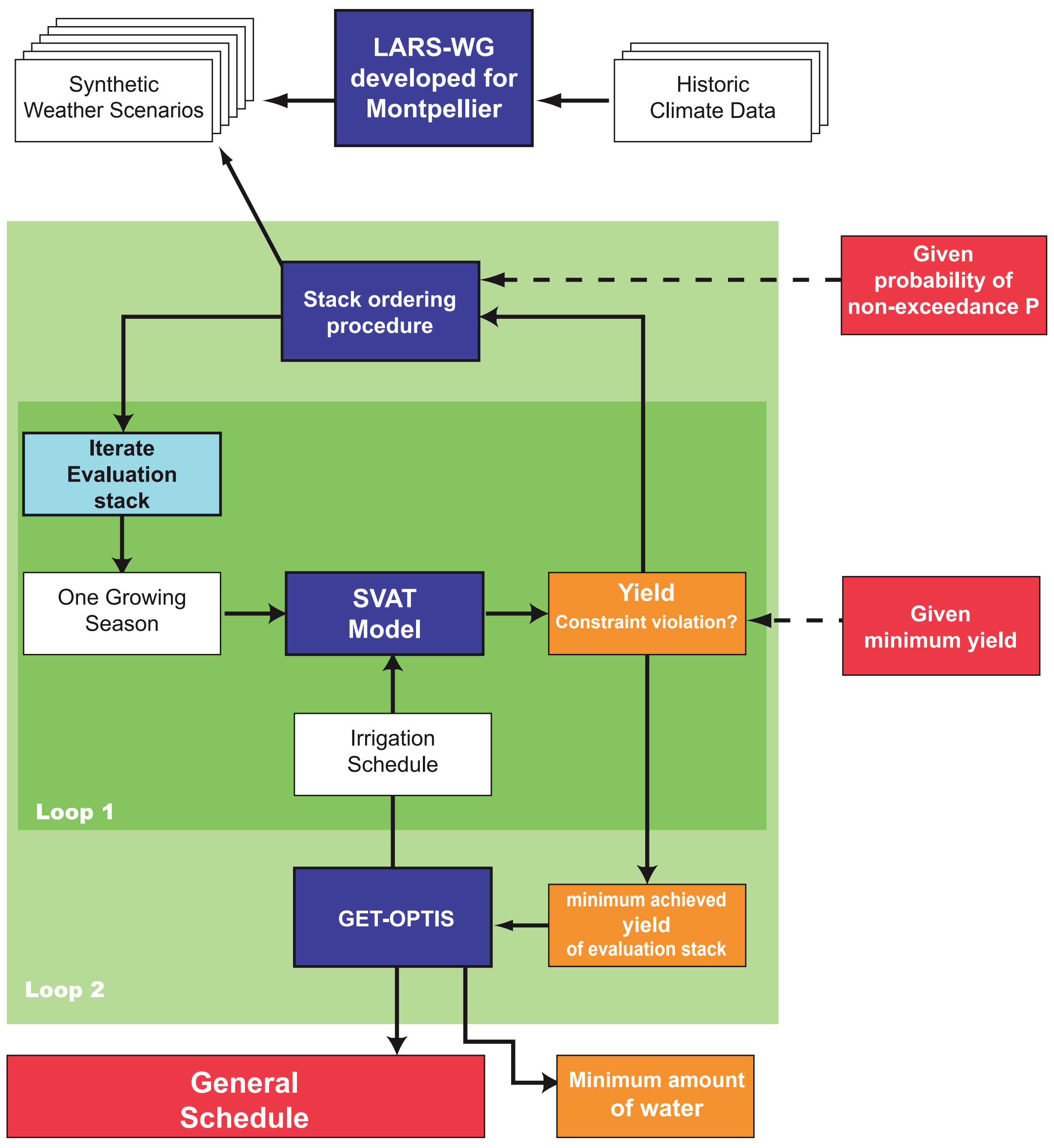
evaluation of the realizations in the stack until a critical solution is found

credit assignment

pool of realizations

Figure 2 Principle of the stack-ordering technique [3], modified

2. Approach



LARS-WG developed for Montpellier

Synthetic Weather Scenarios

Historic Climate Data

Stack ordering procedure

Given probability of non-exceedance P

Iterate Evaluation stack

One Growing Season

SVAT Model

Yield Constraint violation?

Given minimum yield

Irrigation Schedule

Loop 1

GET-OPTIS

minimum achieved yield of evaluation stack

Loop 2

General Schedule

Minimum amount of water

Figure 1 Framework of the stochastic scheduling procedure

The weather generator LARS-WG [5] (Fig. 1) provides a desired number of scenarios. Within loop 1, the stack-ordering technique selects the most critical weather scenarios with respect to constraint violations (e.g. simulated yield too low). In loop 2, the irrigation scheduling optimizer GET-OPTIS [4] minimizes the amount of water for the weather scenarios from the evaluation stack while crop growth is simulated by the SVAT model Daisy [2].

The stack-ordering technique speeds up the constraint evaluation process by evaluating only a subset of critical weather scenarios (the evaluation stack). The set of critical realizations is approximated by a heuristic (Fig. 2). A credit value C_r is assigned to each weather scenario. The evaluation stack is filled with scenarios whose credit value is higher than a predefined value S. Remaining positions in the stack are filled randomly. The stack is evaluated in descending order until either a constraint violation is found, which results in an increase of C_r for that scenario, or all scenarios are evaluated, which results in a decreased C_r for all scenarios in the stack.

3. Example and Results

The procedure was tested for a hypothetical agricultural site in the Al-Batinah region (Sultanate of Oman) where maize and sorghum were grown with soil data taken from [1]. 500 realizations of synthetic daily weather over a year were generated from regional historic weather records. A stack size of 50 was used for the stack-ordering technique and tested in 5 independent runs where the minimum amount of water needed to ensure a yield of 8t/ha in 90% of the cases was sought. A Monte Carlo simulation was used for comparing performance and results of the approach.

All 5 simulation runs resulted in yields of 8t/ha and irrigation amounts of 381 to 395mm (Table 1). The achieved water productivities of around 2kg/m³ are significantly higher than observed productivities in the region (below 1kg/m³ [6]). Similar results of the runs also indicate the procedure works robust and converges to nearly identical solutions after approx. 7500 model evaluations.

An optimization run passes through different stages (Fig. 3). Many constraint violations occur in the beginning (red markers) followed by a steep decrease in the value of the objective function with fewer constraint violations. The end marks a fine-tuning where improvements of the values of the objective function alternate with corrections of constraint violations.

The Monte Carlo simulation yielded in similar results but required a total of over 140.000 model evaluations (Fig. 4). General irrigation schedules (Fig. 5) show higher variability compared to the empirical distribution functions (Fig. 6) indicating that there is no single solution optimal for the scheduling problem. This applies for both the stack-ordering techniques and the Monte Carlo simulation.

A general and fixed irrigation management that ensures high yields while using minimum amounts of water is possible for the region, however.

Table 1 Result of 5 different optimization runs (yields and water amounts are 90%-quantiles) for the stack-ordering technique

	Run 1	Run 2	Run 3	Run 4	Run 5
Yield (t/ha)	7.98	8.01	7.99	7.99	8.00
Irrigation amount (mm)	387	398	381	393	395
Water productivity (kg/m³)	2.06	2.01	2.09	2.03	2.02

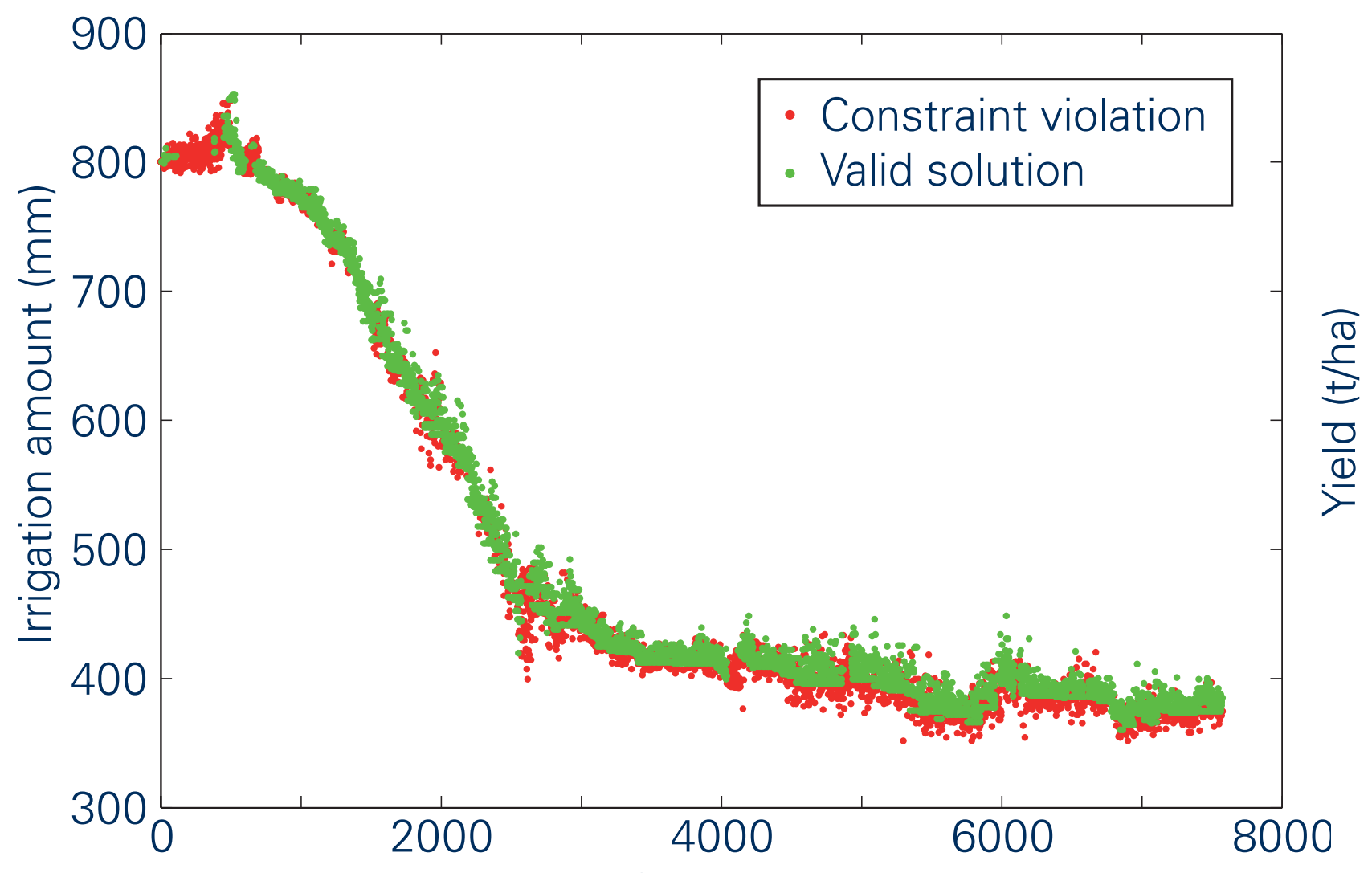


Figure 3 Optimization run for the stack-orderung technique

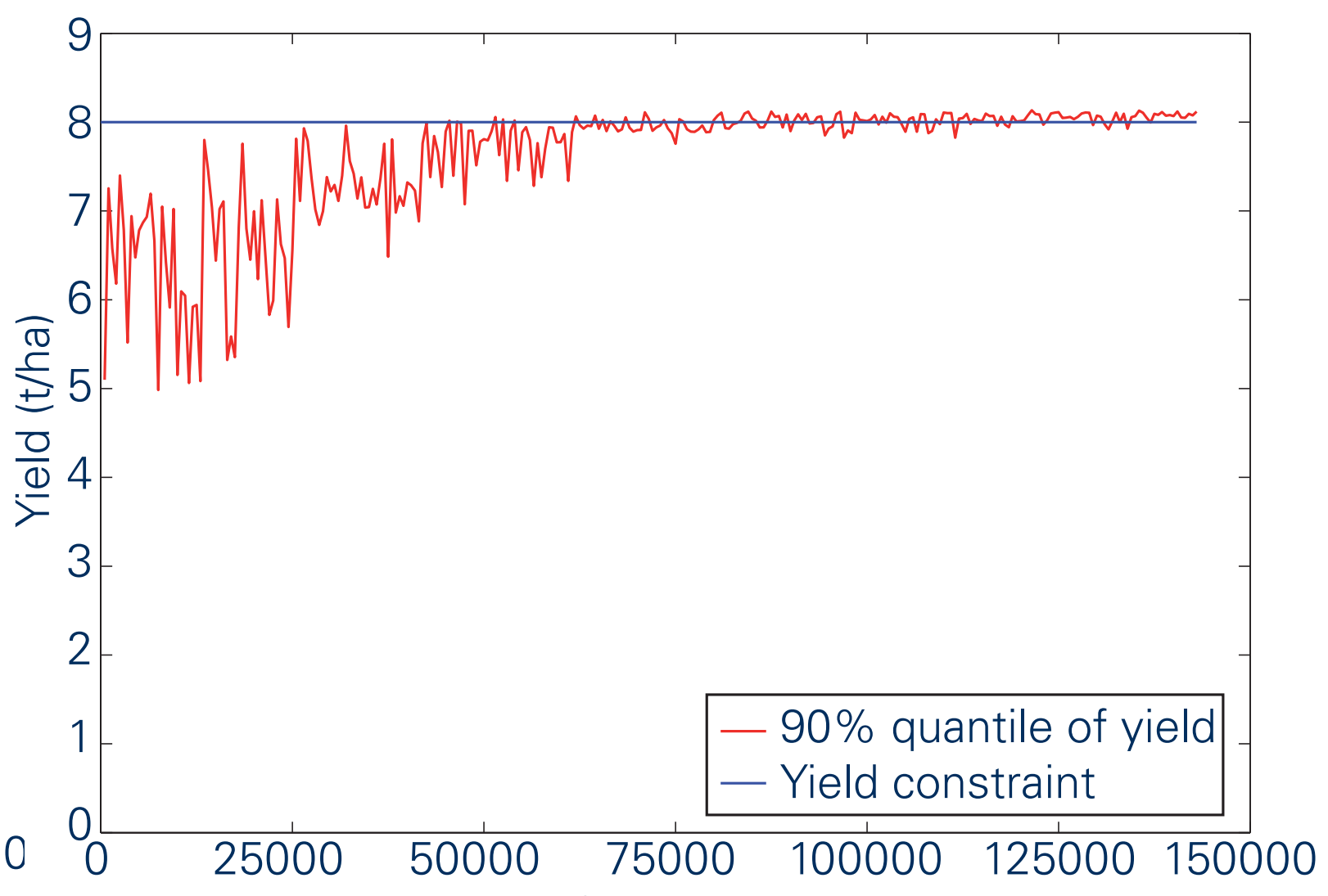


Figure 4 Optimization run for the Monte Carlo simulation

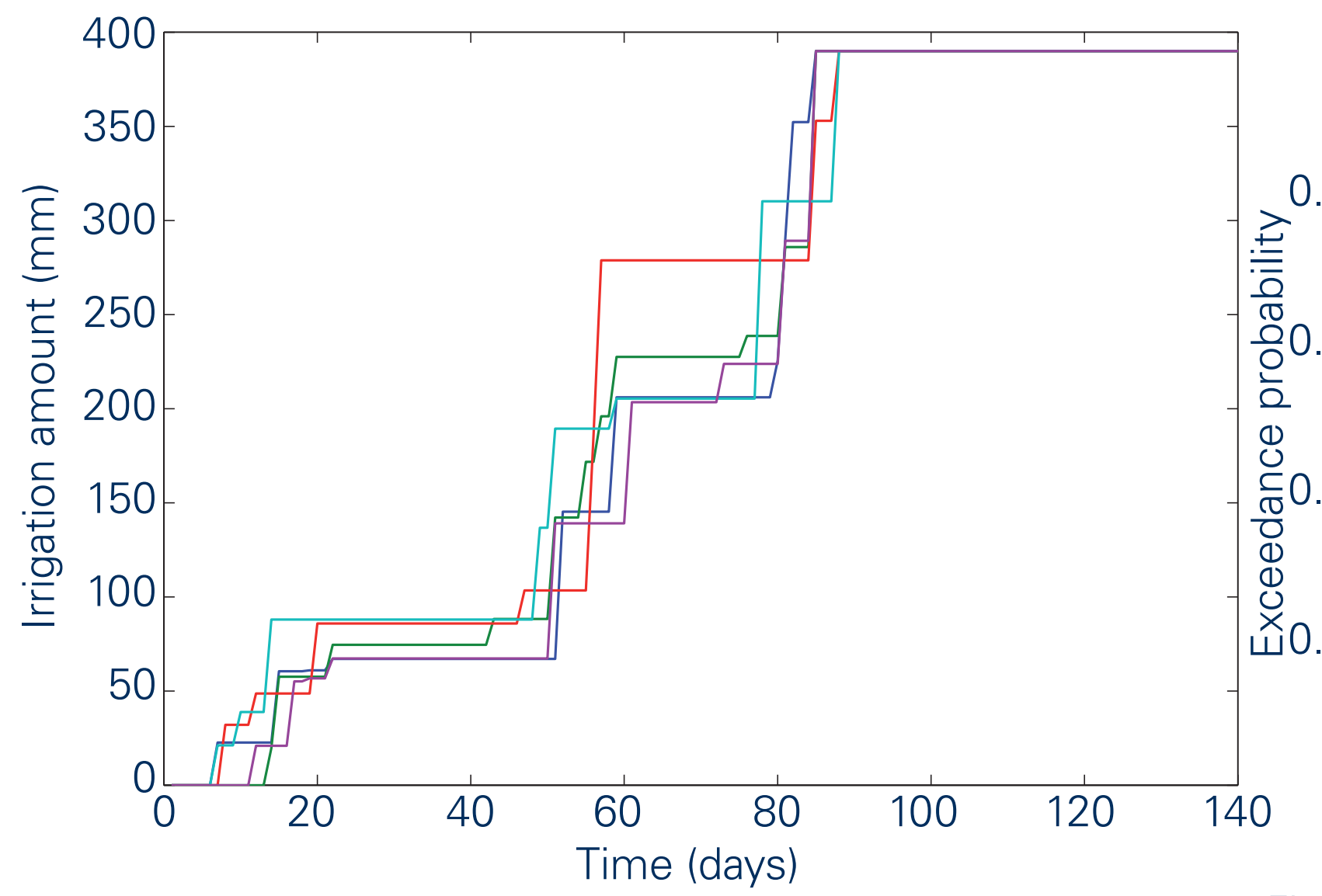


Figure 5 Irrigation schedules of the 5 last optimization runs for the Monte Carlo simulation

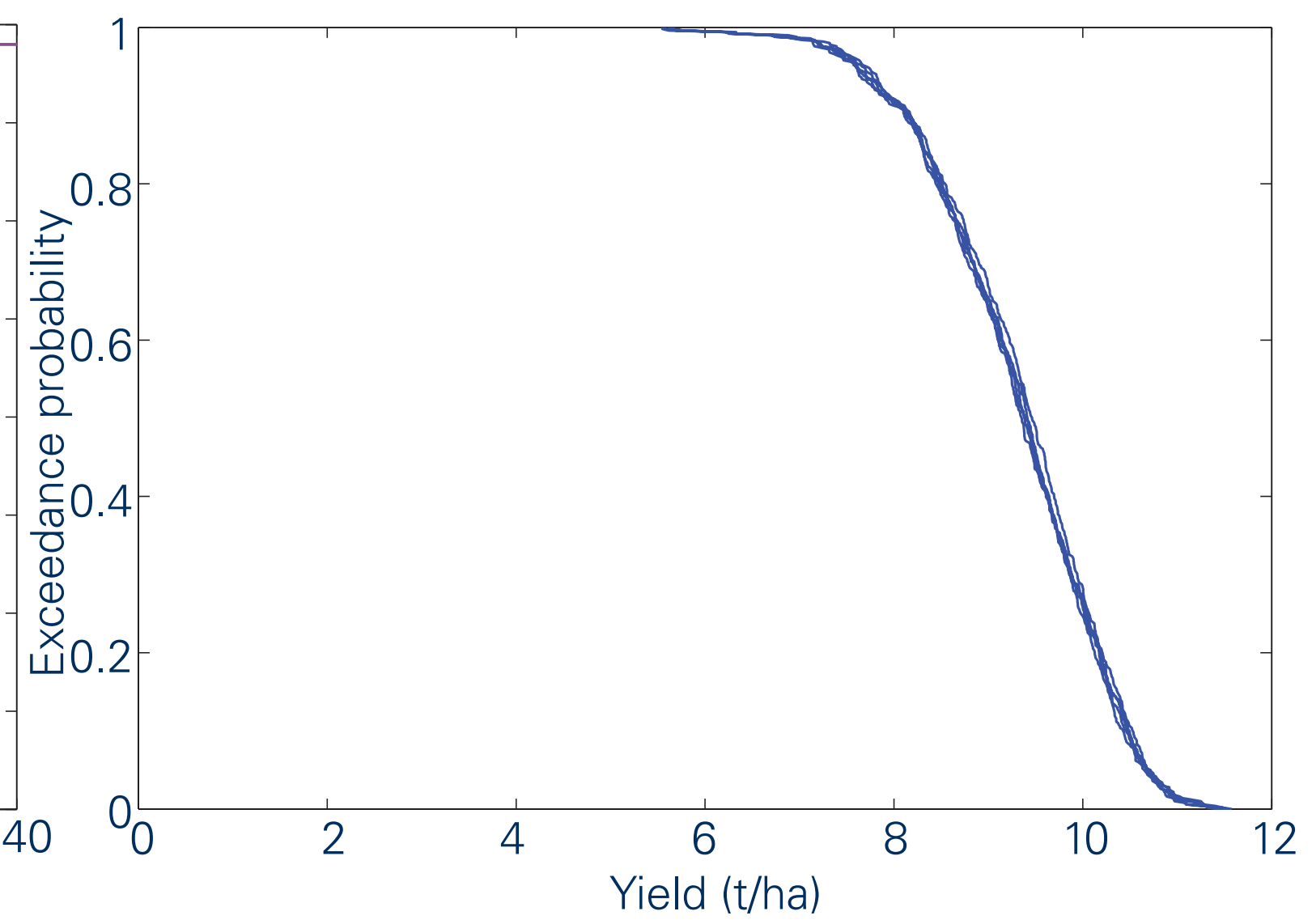


Figure 6 Empirical cdf of the 5 last optimization runs for the Monte Carlo simulation

4. Conclusion

The stack-ordering technique combined with an optimal scheduling algorithm for finding highly reliable solutions to a deficit irrigation problem works well when large numbers of input variables are used to quantify the uncertainty inherent to the optimization problem. With an iterative optimization procedure, the evaluation of the entire set of input scenarios is hardly possible. Instead, only a subset of scenarios is needed for the stack-ordering procedure to find solutions of equal reliability and optimality. The savings in computational costs are more than 90%.

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Contact: Sebastian Kloss
Dresden University of Technology
Institute of Hydrology and Meteorology
01069 Dresden, Germany
Email: sebastian.kloss@tu-dresden.de