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Hydrology and
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Discussions

Interactive comment on "A new approach to model the variability of karstic recharge" *by* A. Hartmann et al.

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We thank anonymous referee #2 for the detailed and very helpful review. Before responding on the specific comments we will address the major concerns:

1. Comparison with already existing approaches:

The authors agree with the referee that a lot can be learned from model intercomparison (MI), which has been a common, but long lasting project in many disciplines (e.g. Snow-MIP). Lange et al. (2010) compared the observed recharge rates at the cave with the recharge rates obtained by a water balance approach conducted by Shachori et al. (1965) for the whole catchment. A comparison to their results will be added to the discussion. However, a more detailed and technical MI is not possible within the

scope of this manuscript. We are not aware of any model application to a comparable data set (sprinkling experiment and natural data on top of a karstic cave and the following simulation of the sum of individual drip responses). Hence, other approaches could only simulate a small proportion of the data set and the comparison would be difficult or unfair, because most are not able to address variability and solely unsaturated processes in karst recharge. Thus we do not want to focus on a comparison to other methods, but rather on introducing a new approach to a unique data set. Commonly, new model approaches have been introduced without comparison to alternatives: Perrin et al. (2003) for the GR4J model or Lindström et al. (1997) for the HBV model. We believe that a detailed MI project of karst models, or karst recharge models, would generally be of high value and interest. The referee and the authors could join forces to initiate a karst MIP, similar to intercomparison studies in Refsgaard and Knudsen (1996), Smith et al. (2004), or Holländer et al. (2009).

2. Necessity of a split-sample test:

The authors agree with the referee that the model has to be evaluated appropriately. The split-sample test (Klemeš, 1986) is a common tool to evaluate calibrated hydrological models. But there are also different ways to evaluate model structures and parameters. Using Monte Carlo sampling, distributions of the model parameters can be established that do not only show their stability but also provide information about their uncertainty (Beven and Binley, 1992). Using the Metropolis approach (Metropolis et al., 1953), Kuczera and Parent (1998) could show that a Monte Carlo Markov Chain sampling is even more rigorous than the spilt-sample test. The authors use a method (Shuffled Complex Evolution Metropolis algorithm SCEM; Vrugt et al., 2003) that is based on the Metropolis approach. In addition, instead of splitting the data in different time periods, a split-information test is performed in this study, i.e. four different types of observations (event drip rates, seasonal drip rates, tracer concentrations and information about variability) are considered. The distributions of the model parameters for the different types of information are shown in Fig. 5 and their uncertainty is discussed in section 5.3. The authors believe that an additional split sample test will not provide more information on model reliability.

3. Discussion about transferability of the new approach:

The authors agree that a more thorough discussion about the transferability of the new approach to other field sites with epikarst and the problem of obtaining information about variability will add more value to the presented study. It is proposed to add an extra subsection 5.5 “Transferability of the new approach” (see below) that addresses the hypothetical performance and parameter values of the new model under different conditions. For that, two different caves will be theoretically considered. One is located in a semi-arid climate in a sloping terrain (Soreq cave, Israel; Ayalon et al., 1998;Even et al., 1986). The other is located in a humid climate in an even terrain but with a deep and complete soil cover (Vers-chez-le-Brandt cave, Switzerland; Pronk et al., 2009). Since the parameters of the new model have a physical meaning, hypothetical changes of the model results can be assessed. The possible lack of information in many potential sites about the variability of recharge dynamics will be addressed by suggesting methods to assess the distribution parameters by other types of information like soil depth distributions or karst evolution models.

In the following the new subsection 5.5 of the manuscript:

5.5 Transferability of the new approach

Even if the introduced model performs well and is physically reasonable under the study site’s conditions, the question about the transferability of the approach to other sites has to be addressed. In detail one has to ask whether the model is able to cope with differences in system properties and whether the model can be applied without information about the variability of recharge dynamics. For that we consider two different caves, (1) the Soreq cave, Israel, and (2) the Vers-chez-le-Brandt cave, Switzerland.

The Soreq cave is located in a semi-arid climate 10-50 m below the surface at a sloping terrain. Using drip rate observations at several observation points within the cave and environmental tracers it was found that, depending on the degree of fractures, distance to the surface and rainfall duration and intensity, fast flow can occur (Even et al., 1986;Ayalon et al., 1998). However, most recharge travels several decades in small fissures before it reaches the cave (Kaufman et al., 2003). Our model already proved that it is able to cope with fast as well as with slow flow paths. However, due to the sloping terrain, lateral flow processes that have shown to be not important at our study site may be of higher significance at the Soreq cave. On such terrain, also surface runoff should be accounted for, as has been shown on a slope nearby (Lange et al., 2003).

The Vers-chez-le-Brandt cave is located below relatively flat pastureland in a humid environment, 30 m below the surface with 1-2m soil on top. Drip rates observations at one observation point in the cave and artificial and environmental tracers showed that its typical dynamics during a rain event are characterized by five phases (Pronk et al., 2009): saturation of the soil, initiation of pressure pulse by perched water, arrival of first event water at the cave, increased amounts of event water at the cave, and recession period. Since our model includes a soil layer and allows for perched water tables, we are confident that our approach will most probably be able to reproduce these five characteristic phases. Compared to our site the soils are much thicker and distributed more evenly. Hence, allowing a deeper soil in the model setup will address this difference. The lack of information about recharge variability could be reduced by directly measuring soil depth distributions (as in Tromp-van Meerveld and McDonnell, 2006). However, information about the distribution of vertical conductivity, water storage or decrease of lateral conductivity with depth is difficult to obtain. To compensate for this, we see a high value in karst evolution studies and models, which provide aperture width distribution depending on climate and degree of fractures before karstification began (e.g.Bloomfield et al., 2005;Hubinger and Birk, 2011).

Reply on specific comments:

1. P.2447: It will be clarified that a detailed description of the observations and their interpretation are presented in Lange et al. (2010) and Arbel et al.(2010). In addition the manuscript will be changed to include a small summary of these studies.

2. Variable units will be included in the manuscript in section 3.

3. P. 2448: The manuscript will be modified to clearly show when we speak of temporal variability and when we speak of spatial variability.

4. P. 2449: The variable that describes the number of model compartments will be renamed. 5. Eq. 10: The compartment number i will be added to Eact(t).

6. P. 2452, line 4: “Qin,surf,i” will be changed to “Qin,surf,i+1”.

7. P. 2452: Yes, Vold,max and Cold can be considered as initial conditions. The manuscript will be modified to clarify this.

8. P. 2453: The authors are aware that using the Nash-Sutcliffe efficiency NSE can result in a small underestimations of peak values and temporal variability when using a automatic calibration routine. Gupta et al. (2009) exemplified this by a rainfall-runoff model using discharge observations, neither by tracer concentrations nor by information about spatial variability. Hence, their concerns might not be directly transferable to our study. In addition, we use NSE to compare the model simulation and parameter distribution. A possible bias would therefore occur in all calibration steps and the comparison would still be possible.

9. P. 2454, line 6-8: the manuscript will be modified to point out that if using only information about drip rates and tracer concentrations, the calibration will result in unrealistic and contradicting values for some of the parameters.

10. P. 2454, line 24: The parameter distribution in Figure 5 shows that these parameters, and their related processes, are not sensitive. Hence, fixing them would result in no changes to the simulations. The manuscript will be changed to clarify on this.

11. P. 2455, line 4: suggested change will be performed.

12. P. 2455, line 15: the manuscript will be shortened to avoid these repetitions.

13. P. 2458: Extending the upper bound of the old water concentration parameter range was already done during the analysis. This led to much higher calibration values for Cold, but not to a significant change in the model results. Only small improvement of NSC,exp could be reached. Preferring a physical realism instead of optimal fit, it was decided to set the ranges of Cold to the values measured in the field campaigns (Arbel et al., 2010;Lange et al., 2010). The manuscript will be modified to include this information.

14. P. 2459: the discussion will be modified accordingly (see author’s comment on the referees major concern #2).

15. P. 2467: the source of data will be clarified in the manuscript.

16. P. 2470: The sampling scheme of the Shuffled Complex Evolution (SCEM) approach is based on the Metropolis-Hastings approach (Hastings, 1970;Metropolis et al., 1953). A self-adapting proposal distribution is used to search the whole parameter space, which finally results in the parameter distributions in Fig. 5. As already written in section 3.3 the method is well known and a reference to the detailed description (Vrugt et al., 2003) is given, too. Therefore, the authors believe that adding a more detailed description to the manuscript is not necessary.

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