Joint reply to interactive comment on "Does the simple dynamical systems approach provide useful information about catchment hydrological functioning in a Mediterranean context? Application to the Ardèche catchment (France)" by STUDENTS

M. Adamovic et al., January 2015

In the following, the students' comments appear in black italic and our answers are provided in blue.

We thank all the students for their positive appraisal of the paper content and for their constructive suggestions to improve the paper. The reply includes answers to all students reviews, taking into account the major issues they mentioned. All the minor and specific comments will be taken into account when finalizing the manuscript.

As a general comment, we would also like to underline that, after submission of our paper, we were aware of papers by Wittenberg (1999) and Wittenberg and Sivapalan (1999) where recession analyses were applied to estimate groundwater recharge in an Australian catchment with a Mediterranean type climate. Therefore our study is not the first application in this kind of environment. Wittenberg and Sivapalan (1999) pointed out the impact of evapotranspiration on recession estimation. They also showed, that using a stratification of the data set according to the time in the year, it was possible to quantify evapotranspiration losses and groundwater recharge. We will refer to those papers in the revised version of our manuscript and will modify lines 20-21 p10728 as follows:

"To our knowledge, the simple dynamical system approach has not been evaluated in a Mediterranean context, where the rainfall regime exhibits strong contrasts between dry conditions in summer and intense rainfall events, often related to stationary Mesoscale Convective Systems (Hernández et al., 1998), during autumns. Wittenberg and Sivapalan (1999) for instance used recession analyses to estimate groundwater recharge in a Mediterranean type of climate in Australia but they did not consider storage-discharge relationship in its implicit differential form, the discharge sensitivity function g(Q), introduced by Kirchner (2009)".

As a second general comment, we would like to apologize about an error in the reference to the Turc equation. The correct reference is Turc (1951). In this paper Turc presents the formula for AET estimation based on annual average temperature and rainfall, whereas the Turc (1961) papers presents a formula to compute potential evapotranspiration depending on temperature only. This may have led to some confusion, as some students pointed out papers comparing various formula of reference evapotranspiration ET0, and not actual evapotranspiration AET.

In the 1951 paper, Turc reports an evaluation of his formula by comparing measured interannual discharge to values estimated through *P-AET* where *AET* is estimated by formula (2) of the paper with generally good performance. The considered data set was covering countries all over the world. In addition, as described in the paper, one of the reasons for choosing Turc's simple equation for the estimation of AET from P and T in Mediterranean climatic conditions is that it relies only on the P and T and not on ET_0, we could avoid the use of evapotranspiration and reduce uncertainty in estimating AET. In addition, the Turc equation for estimation of AET is widely used in France and thus our results can be compared to other studies we can find other studies for comparison.

Concerning AET estimation in our modeling, we would like to highlight one point which was probably not fully clear in the paper presentation. In fact we assume that $AET = \alpha_{AET} * K_c ET_0$ where α_{AET} is the scaling *AET* factor provided in Table 3 of the original paper. While this scaling factor is assumed to be constant throughout the year, hourly variation (hourly ET_0 signal) and seasonal variations (seasonal K_c) of *AET* are considered. We agree that a mean annual value of α_{AET} is probably too coarse as strong seasonal variations in AET signal are expected due to the seasonal variations of ET_0 and vegetation activity. However, the Turc (1951) formula only provides annual values of AET and the water balance approach (AET=P-Q) that we used as reference is also valid only for interannual averages. The method of Thornwaite and Mather (1955) cited by Gudulas et al. (2013) provides monthly estimates of AET and could be a way to improve our simulations.

General

SC 4848:

Summary
This manuscript by Adamovic et al. presents and evaluates Kirchner's method, which until now has not yet been evaluated in a Mediterranean climate. Rainfall regime in this region can be described with dry spells and drought in summer contrasted with high-rainfall periods in autumn. It therefore focuses on the applicability of Kirchner's method and its limitations; and what we can learn about dominant hydrological processes using this methodology. Most catchments show a large degree of variability and heterogeneity in both space and time, which in turn raise questions about degrees of model complexity in order to describe their behavior. Large-scale equations like Darcy's or Richards' equation might not be sufficient in describing catchment behavior and heterogeneity at catchment scale (Kirchner, 2006). Kirchner (2009) represents a catchment with a simple dynamical model, where system parameters are directly derived from the detected stream flow fluctuations during recession periods. This includes one essential assumption: discharge depends only on the total water stored in the catchment. Until now, this method has mostly been applied in small humid catchments. The four study areas mainly consist of granite and basalts lithology. The results of this manuscript show good discharge simulation for winter (humid) conditions in catchments characterized predominantly by granitic lithology. Under dry conditions, poor model performance is generally related to the disturbed water balance terms, high actual evapotranspiration and imprecise discharge measurements. It's important to know whether this model also holds for other than humid catchments and therefore makes a valuable contribution to the hydrological literature in this field of research.

The general impression is that the article is that tables are clear and graphs are well-illustrated, however the structure could use some improvements. In terms hydrological *modelling it is of great interest for, when applicable, Kirchner's model is easy to use, whereas some of the techniques used to modify the data and timescale used are debatable. This manuscript shows that while the model is applicable to humid conditions in multiple areas, it does not work well in summer. In my opinion it is an interesting article for readers of HESS, however I have a few corrections and minor revisions which, in my opinion, will improve the paper.*

Answer: Student#1 questions the use of average annual temperature and precipitation in estimating AET according to the Turc formulae. As underlined above, annual values were only used for the calculation of the rescaling factors. When simulating hourly discharge, hourly values of rainfall and potential evapotranspiration are used. In addition, reference evapotranspiration ET_0 is modulated using monthly crop coefficients K_c.

The student also questions why the scaling was done for 3 out of 4 catchments in the Ardèche basin. Catchment #1 was not rescaled since the Turc estimates were close to the AET obtained as difference between P and Q.

SC 4850:

Summary

In this study the simple dynamical systems approach proposed by Kirchner (2009) is applied to a Mediterranean catchment: the Ardèche in France. Originally this method was used in two catchments in Wales, characterized by a wet climate. To explore if this approach also works in other climate zones, the authors of this paper used the Ardèche, characterized by strong summer dryness. The results show that the simple model works well for the wet periods, but fails to simulate the discharge well in dry, warm periods.
The paper overall is well written and well structured. It does not present new fundamental science; rather it applies a tried and tested model on a larger, more heterogeneous catchment in a drier, warmer climate, to provide a better understanding of the applicability of this model. It provides a thorough methodology, with fairly well presented results. The paper is definitely relevant for the hydrological community; the original paper (Kirchner, 2009) has presently been cited 111 times, but the concept was never tested in a drier catchment. However some things in this paper could be improved: there are some data quality issues that I feel could have been addressed better. I also think that the (physical) causes of the difference in model results, comparing the different sub-catchments, should be elaborated upon.

My recommendation to the editor is that this paper should be accepted, after proper revision of the mentioned issues.

Answer: Student#2 highlights two main issues in the work: data quality issues and questions about the predictors of hydrological variability.

Regarding the data quality, Student #2 questions the use of the Ardèche catchment instead of using some well-known experimented catchment like the ones used by Kirchner (WRR, 2009). We agree on the interest of well monitored and controlled catchment for scientific studies. However, we were specifically interested in testing tools for understanding the hydrological functioning of catchments, where only operational data are available. Therefore, we found it interesting to see if meaningful results could also be obtained from operational data. The Ardèche catchment is chosen as a case study since there are many operational networks there. This enabled us to identify the problems with measurement networks, on the one hand, and to better understand the catchment functioning taking many climate forcing uncertainties into account, on the other hand. We believe that our results are of interest, as they point out that, provided data uncertainty is correctly handled, the simple dynamical system approach is applicable to Mediterranean type catchments.

Regarding the predictors of hydrological variability Student#2 suggests that the second question in the manuscript should be discussed more thoroughly. We also mention here that the paper will be more re-oriented towards the simple dynamical system approach as proposed by Referee 2.

This remark will be taken into account and will be discussed further in the discussion section. We argue that the fact the catchments #1 and #3 are granitic with many fractures (observed on the field) can be one of the main predictors of hydrological variability which result in rapid subsurface flow. The student however argues that the fact that they are homogeneous plays a more important role than the fact that they are granitic, to which we cannot really agree. For example in some karstic catchments even though they can be considered as homogeneous, the geological formation (karst) could be probably responsible for characteristic runoff response. The role of geology is more thoroughly demonstrated in Adamovic (2014) but providing all the information was beyond the scope of the present paper.

SC 4852:

Summary

The manuscript by Adamovic et al. adjusts the data driven approach of Kirchner (2009) in a Mediterranean environment. This paper provides valuable information and data for the analysis of the Kirchner method in the Mediterranean area. The Kirchner method has already been applied at different locations and environments like Wales (Kirchner, 2009), Alzette (Krier,2012) and the Swiss prealpines (Teuling, 2010). This approach has not yet been assessed in a Mediterranean environment. Therefore I support the publication of the paper, however I suggest some minor improvements. The suggestions are particularly in the analysis of evapotranspiration in the model, taking into account other parameters like hydrophobic conditions in dry environments and the structure of the article.

The study takes places in the Ardèche, France, at four different catchments. The Kirchner method applies an equation where discharge and water storage in a catchment can directly be connected. In this way the precipitation rate can be estimated based on discharge changes. This method is applied in the Ardèche and shows a good simulation of discharge during the wet periods. However, in dry periods (especially summer) the simulation does not correspond well with the observed values. This is probably due to the high influence of evapotranspiration conditions and imprecise measurements during the dry periods. The author suggests to improve the actual evapotranspiration rate in the Kirchner model and to explore more significant parameters on the hydrological cycle, like geology and land use.
Overall the paper is clearly written, however the structure of the article is a bit chaotic. At the beginning of each paragraph a short summary explains clearly the structure of the paragraph. However the wide explanations make it sometimes difficult to find out the main point, for example in paragraph 2 where the Kirchner method (2009) is explained. I think a short clear conclusion at the end of each paragraph will improve the clarity of the paper. More detail about the structure is mentioned later in this review.

The tables of the article are well constructed and adjust comprehension to the article. In general the figures illustrate the model simulations well, however some figures have a overload of information and colours(see specific recommendations).

Answer: Student#3 points out the importance of hydrophobic conditions and surface runoff in a Mediterranean climate. He says that long dry summers can establish the hydrophobic conditions that could eventually lead to the high rate of surface flow. He suggests that these elements could be also implemented in the model. In the current examined catchments however, we implemented also the bypassing flow which resulted in the surface runoff of less than 1% (Adamovic, 2014). This however does not imply that there is no surface runoff, in particular, it has been observed in the field in some agricultural parts of the Ardèche basin.

The student also questions the hypothesis that AET is equal to PET the whole year. Some answers are provided at the beginning of this answer. The student also points out on the reference equation of the Turc we are using in our analysis. Indeed, the right reference is the one from 1951 and not from 1961 where Turc proposes a formula for estimating reference evapotranspiration. This will be corrected in the article.

SC 4854:

Summary:

The paper is mostly well written and tables and figures are often clear and useful. However, I still have some remarks. The first remark is about the assumption to take non-vegetation periods during night-time to be able to neglect evapotranspiration. This assumption will have the largest effect on discharge in summer, as evapotranspiration will be relatively high. A *second remark is about the determination and improvement of the parameters C1, C2 and C3 and the used data for this determination. The last major issue has to do with the structure of the manuscript and answering the second main question. Minor remarks are given on formulation of assumptions and some results. In addition, I have some small remarks on lay-out and typos. After these minor revisions, my advice is to accept the manuscript for publication.*

The manuscript by Adamovic et al. examines the applicability of the simple dynamical systems approach of Kirchner (2009) in order to characterize the Mediterranean catchment the Ardèche and takes a look at the limitations of this method. It also investigates what the use of this methodology can tell about dominant hydrological processes in the catchment. For this, the discharge sensitivity function is estimated and used in a simple model to simulate measured discharge. Whether this model can simulate discharge and retrieve rainfall is then tested. This manuscript shows that simulation of discharge especially in wet periods can be done rather well in the Mediterranean climate and will therefore be of interest for readers of HESS. Personally, I think it is really interesting that based on only a few variables, namely precipitation, actual evapotranspiration and an initial discharge measurement, discharge can be well simulated in wet periods for humid as well as drier climates.

Answer: Student #4 pointed out that neglecting evapotranspiration during night-time and non-vegetation periods should be explained in more details. He says that even in these selected periods, there is evaporation from soils and that adaptation of the simple dynamical system model to nocturnal evapotranspiration conditions should be elaborated further in Discussion section. In the Ardèche catchment there is a clear diurnal cycle seen in discharge as mentioned in the manuscript. In order to avoid as much as possible distortion of recession curves by evapotranspiration, we chose non-vegetation periods (November-March) as periods for robust parameter estimation in the current Mediterranean conditions.

The student also pointed out that the g(Q) function is estimated from the whole examined period 2000-2008 and that the discharge simulations are then reproduced for the same time period. In the manuscript however, the g(Q) function is estimated from the non-vegetation periods (during night time and when there was no rain) which represent only a small sample of the hydrograph. Then the discharge simulations are done for the whole period (2000-2008). This is going to be explained more clearly in the manuscript.

The student also points out the work of Melsen et al. (2014) where the authors concluded that one winter season (November until March) can give reasonable results with two-parameter model in a small Alpine catchment (3.31 km^2). The Ardèche catchments, however are much larger and more heterogeneous in terms of geology and land-use. The climate forcing and hence discharge varies from year to year. In order to take this variability into account and to have more robust and more representative results, the nine-year non-vegetation period is selected for the application of simple dynamical system approach. Melsen et al. (2014) also concluded that a two-parameter model is reasonably able to capture high flows but they fail to describe the low flows. In our analysis we used the three-parameter model where the third parameter C_3 is essentially related to the low flows in order to capture the catchment behavior in that flow regime. Eventually, both works pointed out the importance of selecting the non-vegetation periods for estimating the g(Q) function due to the high evapotranspiration conditions in the rest of the year.

SC 4856:

Summary:

This paper studies whether the simple dynamical systems approach can provide useful information about catchment hydrological functioning in a Mediterranean context (the Ardèche catchment). Since catchments show a high degree of heterogeneity and variability, questions are raised about the degree of complexity that must be used to model their behavior. Recently, Kirchner showed that a simple model can suffice, in which discharge is only based on the amount of storage in the system. However, this method has not yet been evaluated in a Mediterranean context, making this study a potential benchmark for application of the method in Mediterranean catchments.
Adamovic et al. concludes that the Kirchner approach works best in wet periods with low evapotranspiration. In periods with high evapotranspiration, this approach is not able to correctly predict the discharges. While these findings are in line with other studies, the manuscript nonetheless makes a significant contribution.

I found three points which will improve the performance of the model (the used SAFRAN data, the Turc equation and surface runoff). By including surface runoff, a review on whether the Turc equation gives satisfying results (with or without a correction on the temperature) and by presenting the known SAFRAN errors, the quality of the research will increase.

Answer: Student #5 sheds light on the use of SAFRAN data in the paper, agreeing with the use of SAFRAN reanalysis (Quintana-Segui et al., 2008, Vidal et al., 2010) for our catchments. However, Student#5 also suggests highlighting the possible consequences of the use of such data in the data presentation section and not only in Discussion. This remark will be taken into account in the final manuscript. SAFRAN data are derived from 8 by 8 km^2 grids on a 6-hour time scale. As mentioned in the manuscript, the SAFRAN data underestimate precipitation in mountainous regions. However, they cover the whole examined area which represents one of the advantages of this data-set.

Student#5 also questions the use of Turc actual evapotranspiration in current Mediterranean conditions. He makes a comparison with the works of Kisi (2013). This paper gives a comparison of different empirical methods for estimating daily reference evapotranspiration in Mediterranean climate. In our study, however we are using the actual evapotranspiration, defined as $AET = \alpha_{AET} * K_c ET_0$ where α_{AET} is the scaling *AET* factor provided in Table 3 of the original paper, K_c is the crop coefficient and ET_0 is a reference evapotranspiration computed using Penman-Monteith equation and FAO parameterization with the SAFRAN climate data.

Hence, our work makes a comparison between different methods for estimating actual evapotranspiration (not reference evapotranspiration), and thus the comment by Student#5 is not directly relevant. Similarly, student#5 also makes a reference to the work of Gudulas et al. (2013). This work makes a comparison between the Thornthwaite equation for estimating actual evapotranspiration and the Turc actual evapotranspiration. Gudulas et al. (2013) also mentioned a need for the temperature factor T_c in order to get similar values between Thornthwaite equation and the Turc equation. The use of this corrected temperature was tested in for catchment #1, and resulted in a value of annual AET 25mm lower than when annual average temperature was used. They also pointed out that the Turc equation for estimating the actual evapotranspiration is favorable in regions where precipitation is higher than 700 mm per years which is the case in the Ardèche catchment.

The last remark student#5 highlights is the use of surface runoff in the catchments. He argues that in catchments such is the Ardèche, dry conditions can eventually lead to hydrophobic conditions, and thus possible surface runoff. Our study concerns upstream/mountainous catchments mostly covered by forest and characterized by steep slopes. Hence, hydrophobic conditions are not likely to occur. We have also implemented bypass flow (Kirchner, 2009) in our model and results show that in the examined catchments, bypass flow (surface runoff) represents less than 1% of the total runoff; thus it can be neglected in the present study (Adamovic, 2014). However, in the downstream part of the Ardèche catchment which is mainly covered by agricultural areas and shrubs, these conditions might occur, which could also be studied in future work.

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