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 Referee#1

M. Adamovic et al., January 2015

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

General:

1) The manuscript presents the implementation of the Kirchner's methodology for describing a catchment as a "simple dynamical system" in several Mediterranean catchments in France. The implemented methodology is rather new and I support its implementation in different hydrogeological or climatic settings. This would undoubtedly contribute to its further development and identification of the possible limitations such as the ones presented in this paper.

In my view, the most important aspect of the paper is the fact that the hydrological data from the operational network ("lower" quality data) has been used in the study.

Therefore, the study might presents possible way how the "official" state hydrological monitoring network data could be used for implementing the methodology presented by Kirchner (WRR, 2009).

It is known that hydrological model performance generally decreases if there are substantial differences (errors) in the water balance; namely, the water balance presents a basis for most of the hydrological modelling efforts. If the simulation is derived directly from the mass balance (the case of the Kirchner methodology), then the water budget related problems become even more pronounced. The authors have demonstrated that the main limiting factors for the application of the methodology in Mediterranean climatic conditions is limited assessment of the actual evapotranspiration. I believe this should be more clearly pointed out in the paper.

Answer: We thank Referee#1 for this positive appraisal of the paper content and for his constructive suggestion to improve the paper. The issue of the assessment of actual evapotranspiration and its impact for the method application was underlined by all the reviewers of the paper (see also remarks 2 and 3 by Reviewer 1 and specific comments by Reviewer 2). Therefore this question will be more discussed in the revised version of the paper.

2) Related to the comment above, the simplified relation that yearly AET = PET might work on a yearly basis, but might be highly questionable during different seasons.

This hypothesis is in my view the main reason that the simulation results are poor during summer. AET rates were found to be substantially underestimated in cases of numerous Mediterranean catchments. This is indicated by the runoff coefficients for the summer rainfall events in the Mediterranean catchments which are extremely low (e.g. see the values reported by Llorens, 1997 (J. Hydrol); Rusjan et al., 2008 (J. Hydrol); Šraj et al., 2008 (Agr.

Forest. Meteorol); Cognard-Plancq et al., 2001 (J. Hydrol); Boronina et al., 2005 (Hydrol. Process); Cosandey et al., 2005 (J. Hydrol). It would be informative to present some representative data on e.g. monthly budgets of the hydrological cycle (P, Q, PET, AET-derived as a difference between P and Q) as this would probably disclose the problems related to the water balance.

Answer: First, 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 a reference is also valid only for interannual averages. The method of Thornthwaite and Mather (1955) cited by Gudulas et al. (2013) provides monthly estimates of AET and could be a way to improve our simulations.

In order to highlight the impact of evapotranspiration in Mediterranean catchments we provide a Table 1 with average monthly budgets of the hydrological cycle (P, Q, ET0, AET) for the Ardèche at Meyras (#1) catchment for period 2000-2008. In order to compute AET at the monthly scale we use the Thornthwaite method (Gudulas et al., 2013), see Table 1.

As remarked by Referee#1 the runoff coefficients in the summer period are extremely low (in July, C=0.17 and in August, C=0.10) with reference SAFRAN ET_0 reaching its maximum in these months. There is a clear strong influence of evapotranspiration in summer periods that could be one of the explanations for the poor modeling performance in these periods. This part will be further clarified in the Discussion section of the paper as proposed by Referee#1.

The water balance calculation at the monthly scale suggested by rReviewer#1 (AET=P-Q) leads to inconsistent values of AET (negative) due to the fact that change in water storage is no more negligible. This is also the main reason why we used an annual scale in rescaling AET afterwards.

Month	**P [mm month^{-1}]**	**ET_0 Safran [mm month^{-1}]**	**Q [mm month^{-1}]**	**Runoff coeff. C**	**AET (Gudulas et al., 2013) [mm month^{-1}]**
Jan	77	23	91	1.18	3.7
Feb	45	31	60	1.33	4.5
Mar	61	53	64	1.05	15.9
Apr	138	70	104	0.75	27.3
May	138	96	88	0.63	54.5
Jun	72	127	36	0.49	74.2
Jul	63	135	11	0.17	82.3
Aug	118	112	12	0.10	81.8
Sep	151	75	32	0.21	61.4

Oct	285	42	121	0.42	44.8
Nov	310	26	264	0.85	19.2
Dec	162	20	175	1.08	6.5

Table 1. Monthly budgets of the hydrological cycle for the Ardèche at Meyras (#1) catchment

The paper will be modified in order to present and discuss this issue and present assumptions more clearly.

3) The annual assessment of AET and consequent mass balance analysis (consistency) relies strongly on the Turc (1961) methodology. Can authors provide some information that would support the implementation of the Turc simple equation for the estimation of AET from P and T in Mediterranean climatic conditions?

Answer: First of all, 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 estimating AET from 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. 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 covered 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 due to equation content. Relying 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 is widely used in France to estimate AET, and thus our results can be compared to other studies.

4) The authors stated throughout the paper that the hydrological response of granite catchments is dominated by the saturation excess runoff. In terms of the conceptual understanding of the rainfall runoff formation mechanisms, the saturation excess runoff probably bypasses the catchment storage as defined by Kirchner (WRR, 2009).
How then the hydrological response of the catchments presented in this paper agrees with the hydrological characteristics, where the original methodology was developed?
Could this also be one of the reasons for worse simulation performance?

Answer: Reviewer#1's comment shows that our reference to saturation excess runoff was not clear enough. In fact, in the granite and forested catchments of this region, infiltration capacity is generally very high and runoff occurs due to soil saturation (e.g. Tramblay et al., 2010). However, this saturation mostly occurs at the interface between the very thin soil and an altered bedrock, generally of larger depth, where contrasts of hydraulic conductivity can be encountered, leading to quick lateral sub-surface flow. Experiments are currently being conducted on infiltration plots to quantify the velocity of this lateral flow (see Braud et al., 2014 for their description). Therefore the main mechanism we are speaking about is quick lateral sub-surface flow which transits through the reservoir considered in the Simple

Dynamical System approach. On agricultural areas, in the intermediate part of the Ardèche catchment, infiltration excess surface runoff is likely to occur (and has been observed in the field). Its contribution is also under investigation using detailed experiments (see Braud et al., 2014). At the whole Ardèche catchment scale, Adamovic (2014) tried to introduce bypass flow in the discharge simulation, but found that this only marginally improved the model performance. In addition, the optimized value of the bypass fraction was about 1%, which is very low.

In conclusion, we acknowledge that the term "saturation excess runoff" is probably not the best suited to describe the processes occurring in the Ardèche catchment but rather shallow subsurface flow caused by saturation of at interface between soil and bedrock. This latter process is consistent with the SDSA approach.

Specific comments.

1) Page 4, lines 31-32: The sentence needs grammar revision.

As the pdf version of the manuscript provides line numbers until line 25 only, we were not able to identify with certainty the above mentioned sentence. Assuming that is sentence page 10732, l 5-6, the sentence:

For our study, we need discharge data that are not influenced by human activity, as Kirchner's method assumes mass conservation. WAS CORRECTED TO:

<u>Answer:</u> For our study, we need natural discharge data that are not disturbed by dam operations or other anthropological factors, in order to apply the simple dynamical systems approach.

2) Page 5, line 26: What are the "main terms" of the water balance?

<u>Answer:</u> Under the main terms of the water balance we consider discharge, evapotranspiration and precipitation. As we consider interannual values, change in water storage is assumed to be zero. This was corrected in the revised manuscript.

3) Page 8: How was the rainfall data consistency performed? On what temporal step (hourly, daily sums?)

<u>Answer:</u> We assume that the reviewer refers to sentence p 10734 lines 4-6. The rainfall data consistency was assessed at the hourly time step. This was corrected in the revised manuscript.

4) In my opinion, table 3 contains extensive list of coefficients that are not properly addressed and consequently extremely difficult to follow in the manuscript, the results presented in the Table 3 are also not properly presented. Most of the studies in the Mediterranean *catchments report highly underestimated rates of the PET compared to AET derived from P-Q mass balance.*

Answer: Please see answer to general comment 2). In addition, in order to make Table 3 clearer, the table was divided into two Tables. One table provides the information about the main terms of the water balance equation (P, Q, C, AET, ET_0, K_cET_0), and the second table gives details about coefficients and corresponding rescaled variables (AET_{Turc}, T, P_{Turc}, C_{Turc}, C_n). They are also more clearly introduced throughout the manuscript as proposed by Referee#1.

Table 2. Hydro-climatic characteristics of the four examined Ardèche sub-catchments (2000-2008).

Catchment ID	**#1**	**#2**	**#3**	**#4**
Catchment name	**Ardèche at Meyras**	**Borne at Nicolaud Bridge**	**Thines at Gournier Bridge**	**Altier at Goulette**
Precipitation (mm yr^{-1}), *P*	1621	1633	1892	1176
Streamflow (mm yr^{-1}), *Q*	1057	1579	970	932
Runoff coefficient, *C*	0.65	0.97	0.51	0.79
Actual Evapotranspiration (mm yr^{-1}), $AET_{wb}=P-Q$	564	54	922	244
ET_0 SAFRAN (mm yr^{-1})	809	792	860	775
K_cET_0 (mm yr^{-1})	731	729	762	699

Table 3. Scaling hydro-climatic characteristics of the four examined Ardèche sub-catchments (2000-2008).

Catchment ID	**#1**	**#2**	**#3**	**#4**
Catchment name	**Ardèche at Meyras**	**Borne at Nicolaud Bridge**	**Thines at Gournier Bridge**	**Altier at Goulette**
Turc Actual evapotranspiration (mm yr^{-1}), AET_{Turc}	609	505	571	475
Runoff coefficient, C_{turc}	0.62	0.69	0.70	0.60
Temperature (^{0}C), *T*	11.2	8.0	9.9	7.7
P_{Turc} (mm yr^{-1})	-	2084	1541	1407
Scaling *P* coefficient	-	1.27	0.81	1.2
Scaling *AET* coefficient	-	0.69	0.75	0.68
New runoff coefficient, C_n	0.65	0.76	0.63	0.66

5) Page 10, lines 22-23: What would be a "realistic" runoff coefficient for analyzed type of catchments?

Answer: We assume that the reviewer refers to sentence p 10737 l 13. We agree with the author that term "realistic" deserves better explanation. In our analysis, the runoff coefficient is another way to reflect the water balance closure in our catchment. This type of catchment is characterized by mountainous and Mediterranean influence. A low runoff coefficient indicates water losses (arid catchment). We consider as realistic runoff coefficients those ones that differ slightly from the runoff coefficient obtained at the catchment #1 where we did not used rescaled data. All examined catchments are located not so far from one another and we consider that runoff coefficients here are in the same range between 0.65 and 0.76 (see C_n coefficients in Table 3 above). Another work (Coussot, 2015), that extends the application of Kirchner (2009) approach to other gauged catchments of the Cévennes-Vivarais region, has obtained similar results. It shows that, once scaled data are considered, there is a quite continuous variation of runoff coefficient throughout the Ardèche and neighbouring catchments (Gard, Céze, Tarn). In addition, in the Ardèche, "naturalized" daily discharges for the gauges influenced by dams were available and the runoff coefficient obtained for those gauges are consistent with the range provided in Table 3 above. Runoff coefficients have generally higher values in the upper part (0.63-0.80) and lower values in the downstream parts of the catchments (0.57-0.60).

6) Page 9, lines 27-28; Figure 4: What represent lines and crosses? How can AET/P in Fig. 4 range between 1.5 and 3 if the y-axis representing the AET/P ratio ranges between 0.1 and 0.7?

Answer: Referee#1 is correct that Fig. 4 needs some further clarification. The values 1.5 and 3 present the values of *w* parameter and not the range of AET/P in Fig. 4. This clarification is taken into account in the revised version of the article.

7) Authors show only the recession rates for catchment #1 (Fig. 5), it would be interesting to see graphically, how the recession rates (described by quadratic curve fitting reported in Table 5) differ between different catchments.

Answer: Here we give recession curves for catchments #2, #3 and #4 as a complement to recession curves given in an original manuscript. We observe that parameters C_1 and C_2 slightly differ among the catchments with C3 parameter being similar for catchments #1, #2 and #3. A more linear relation is seen for catchment #4, which is dominated by schist and basalts geological formations. However, we keep the quadratic function as representative for all catchments. Melsen et al. (2014) concluded that a two-parameter model is reasonable able to capture high flows but they fail to describe the low flows. In our analysis we thus 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.

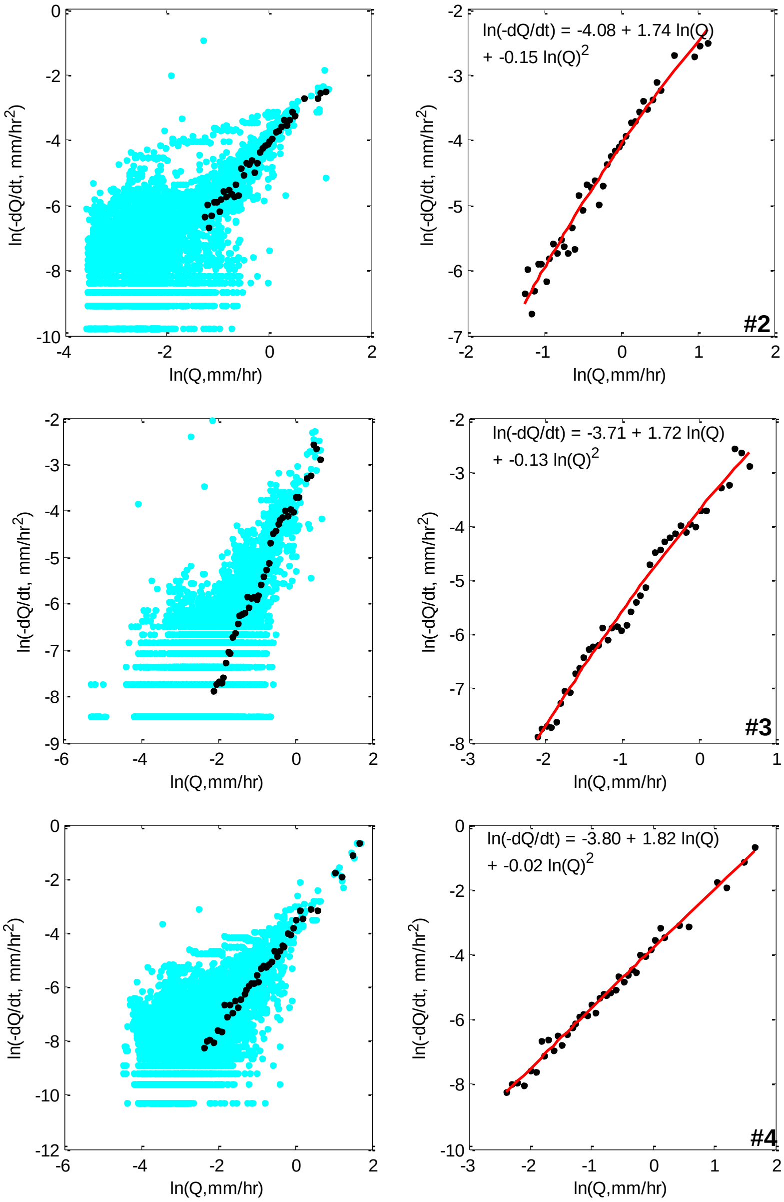

Figure 1. Recession plots for catchments #2, #3 and #4 for all non-vegetation periods between 2000 and 2008; (left) Flow recession rates ($-dQ/dt$) as a function of flow (Q) for individual rainless night hours (blue dots) and their binned averages (black dots). (right) Quadratic curve fitting with binned means.

8) Page 26, line 6-22: The links between the recession curves and hydrogeological characteristics could be more thoroughly presented. How are the characteristics of the catchments reflected in recession rates? This is only roughly mentioned in the paper and would, in my opinion, need a more thorough discussion.

Answer: This remark can be put close to General remark 8 by Reviewer 2 who points out that, although announced as an objective, the paper deals only superficially with the interpretation in terms of hydrological functioning of the Ardèche catchment. Therefore, we decided to change the title of the paper for “Assessing the simple dynamical systems approach in a Mediterranean context? Application to the Ardèche catchment (France)”.

However we also agree with Reviewer 1 that the interpretation in terms of hydrogeology should be better introduced. To hierarchize the influence of several predictors of the catchment response (and values of C_1, C_2, C_3 parameters), Adamovic (2014) used Factor Analysis of Mixed Data (FAMD). By using this statistical technique along with HCPC (Hierarchical Clustering on Principal Components) analysis, geology was found to be the only dominated predictor of runoff variability. The role of geology is more thoroughly demonstrated in Adamovic (2014) but providing all the information was beyond the scope of the present paper.

9) Table 10: The station names should be supplemented with catchment No. as these are referenced throughout the paper.

Answer: This is corrected in the article.

10) Figures 8 and 9: My impression is that there are too many curves shown in the same graph that do not provide any additional valuable information.

Answer: We agree with the Referee#1 that number of curves in Figs. 8 and 9 should be reduced. This is modified in the newer version of the article as shown in the Figs. below, where the range of discharge simulations is represented by a grey area. The lower and upper bounds lie within the range of “behavioral” values (see Table 9 in the original manuscript).

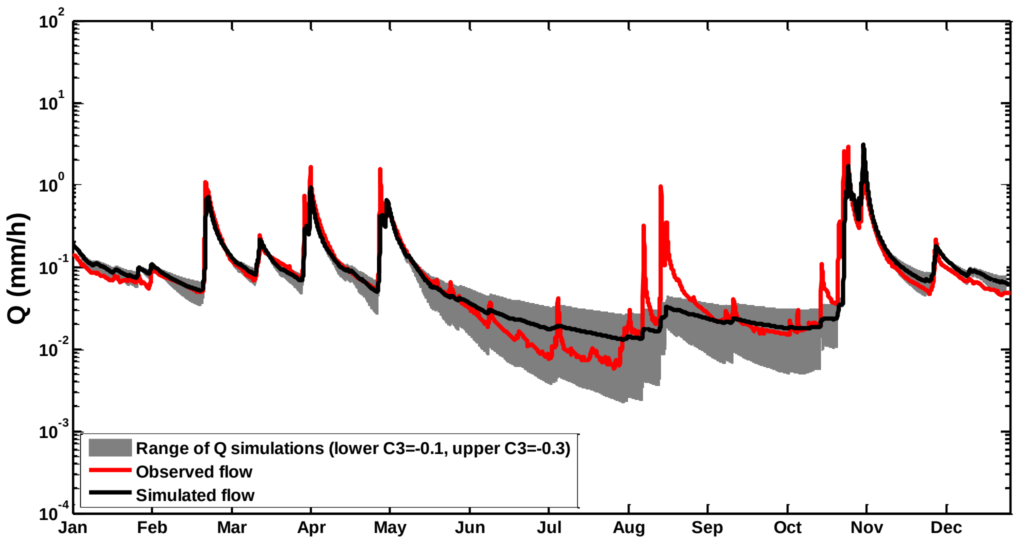

Figure 8. Observed versus simulated hydrograph (C_3=-0.2) for the Ardèche at Meyras (#1) catchment (year 2004), with C_3 parameter variations (C_1 (-3.74) and C_2 (0.65) values are kept constant). The grey area shows the range of discharge simulations.

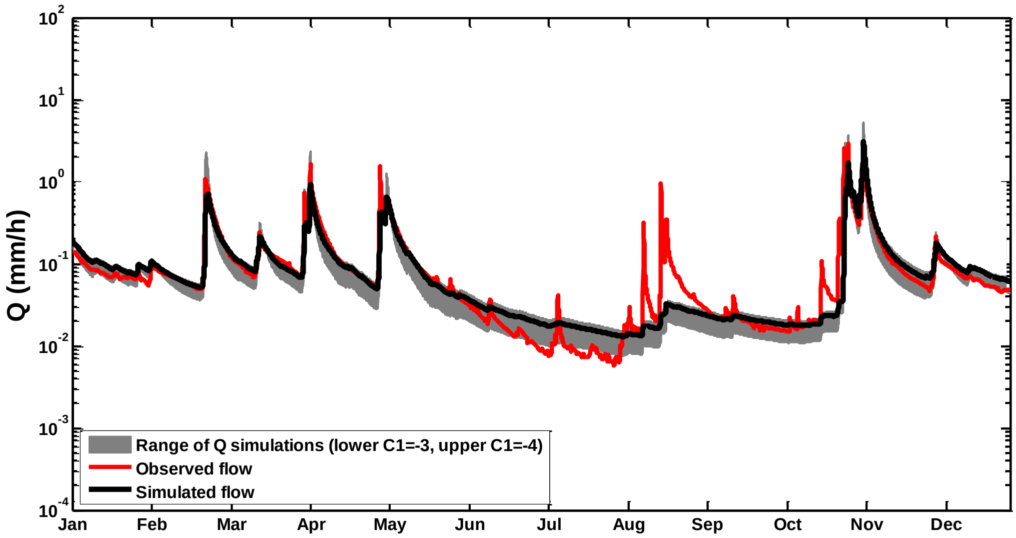

Figure 9. Observed versus simulated hydrograph (C_1=-3.74) for the Ardèche at Meyras (#1) catchment (year 2004) with C_1 parameter variations (C_2 (0.65) and C_3 (-0.2) values are kept constant). The grey area shows the range of discharge simulations.

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