Reviewer 1, Guillaume Evin

I thank the authors for this interesting paper on the relationship between meteorological forcings and soil moisture in the Mediterranean region. The manuscript is well written, well organized and the different modelling tools are adequately applied. The first important result is that the increase in temperature is not the main driver of the changes in soil moisture, but seems to be precipitation characteristics. The second important contribution is methodological since this study shows how a soil moisture model and meteorological scenarios can be used to assess the sensitivity of the soil moisture to these forcings. I have two major comments (see below) regarding how rainfall scenarios are generated. The authors simulate changes of intermittency using the parameter lambda of the Neyman-Scott model. This lambda parameter is the master Poisson process parameter and is directly related to the frequency of rainfall events. I think that the interpretation of 'intermittence' is misleading, which is annoying since the main results of the paper rely on this interpretation. My main recommendation is thus to change the way rainfall scenarios are generated. In my opinion, the best option for the generation of scenarios would be to recalibrate the NSRP model for each set of rainfall statistics (the observed ones + the perturbed ones). In the current version of the manuscript, it must be clearly understood that when one parameter (e.g. lambda) is modified, it affects all rainfalls statistics, which complicates the interpretation of the main factors leading to changes in the soil moisture.

Thank you for this in-depth review of the manuscript and in particular of the stochastic generation method applied in our work.

We acknowledge the concerns raised by the approach considered. While it is true that some authors applied this re-calibration of the rainfall generator after the modification of rainfall statistics (Burlando and Rosso, 2002; Bordoy and Burlando, 2014), other studies considered a similar approach as ours, by modifying directly the parameters of interest in the rainfall generator (Onof and Wheater, 1994; Wasko et al., 2015).

We tested the approach proposed, based on the recalibration of the generator, but this approach did not provide satisfactory results. We also improved the calibration of the rainfall generator. Please find a more detailed response below.

Burlando, P. and Rosso, R.: Effects of transient climate change onbasin hydrology, 1. Precipitation scenarios for the Arno River Basin, central Italy, Hydrol. Process, 16, 1151–1175, 2002.

Bordoy, R. and Burlando, P.: Stochastic downscaling of climate model precipitation outputs in orographically complex regions: 2. Downscaling methodology. Water Resources Research, 50(1), 562–579. https://doi.org/10.1002/wrcr.20443, 2014

Major comments:

#1 Due to its structure, the different parameters of the Neyman-Scott rectangular pulse model are not directly interpretable in terms of rainfall statistics. In the current version of the manuscript, parameters lambda and xi are loosely interpreted in terms of "intermittence" and "mean intensity". In my opinion, this interpretation is incorrect and misleading: - The parameter lambda, which governs the master Poisson process, represents the rate of rainfall events (storms). As such, the mean intensity (for any aggregation duration) is linear in lambda (Eq. 2.5 in Cowpertwait, 1998). It is also true for the covariance for any lag (Eq. 2.6 in Cowpertwait, 1998). This means that when lambda decreases (in this paper the inverse of the storm frequency), the mean rainfall intensity increases in proportion. - The parameter xi is the parameter of the exponential distribution for rain cell intensity. The mean rainfall intensity (for any aggregation duration) is linear in lambda. When xi increases, the mean rainfall intensity increases in proportion (Eq. 2.5 in Cowpertwait, 1998). An augmentation of 50% in lambda is directly compensated by an augmentation of 50% in xi, which is indicated in Section4.1 (l. 20). However, an increase of xi with the same increase in lambda leads to the same annual rainfall but also to an increase of the mean intensity of the rainy days (which is indicated at l. 21 but not clearly since the authors refer to the "mean rainfall intensity"), and to an increase of the number of dry days. - Intermittency is not clearly defined in the paper. I strongly suggest proposing a definition in terms of rainfall statistics. A stronger intermittence could be, for the same annual rainfall, a higher number of dry days. It could be parametrized with lambda and xi, but also with the other parameters. Note also that the theoretical proportion of dry days can be easily obtained with the NSRP model (see Eq. 9a-9b in Cowpertwait, 1991), using a numerical integration. The two quantities that would be perturbed could thus be "the total annual rainfall" and "the proportion of dry days" (or equivalently the number of dry days), which would have a direct interpretation. - As said above, in my opinion, the only valid option for the generation of scenarios is to recalibrate the NSRP model for each set of rainfall statistics (the observed ones + the perturbed ones). When lambda or xi is modified, it affects many rainfalls statistics at the same time, which complicates the interpretation of the main factors leading to changes in the soil moisture. As the proportion of dry days is

important in this study, it should also be included in the set of rainfall statistics used to estimate the parameters. Cowpertwait, Paul S. P. 1991. "Further Developments of the Neyman-Scott Clustered Point Process for Modeling Rainfall." Water Resources Research 27 (7): 1431–38. https://doi.org/10.1029/91WR00479. Cowpertwait, Paul S. P. 1998. "A Poisson-Cluster Model of Rainfall: High-Order Moments and Extreme Values." Proceedings: Mathematical, Physical and Engineering Sciences 454 (1971):885–98.

We implemented the approach proposed, by first modifying the rainfall statistics, and then recalibrating the rainfall generator based on the modified rainfall statistics.

Figure 1 shows that the characteristics of the generated rainfall time series after the perturbation of the rainfall statistics and recalibration are not consistent with the perturbation of the observed rainfall statistics. For instance, for an increase in precipitation intensity and no change in precipitation intermittence, some stations (Lez, Nar, Pez, Vil) do not show any increase in total precipitation (Fig 1 upper panel).

And regarding the impact on soil moisture, Figure 2 shows that, with this method, an increase in precipitation intensity leads to a decrease in the median soil moisture for most of the stations, which seems unrealistic.

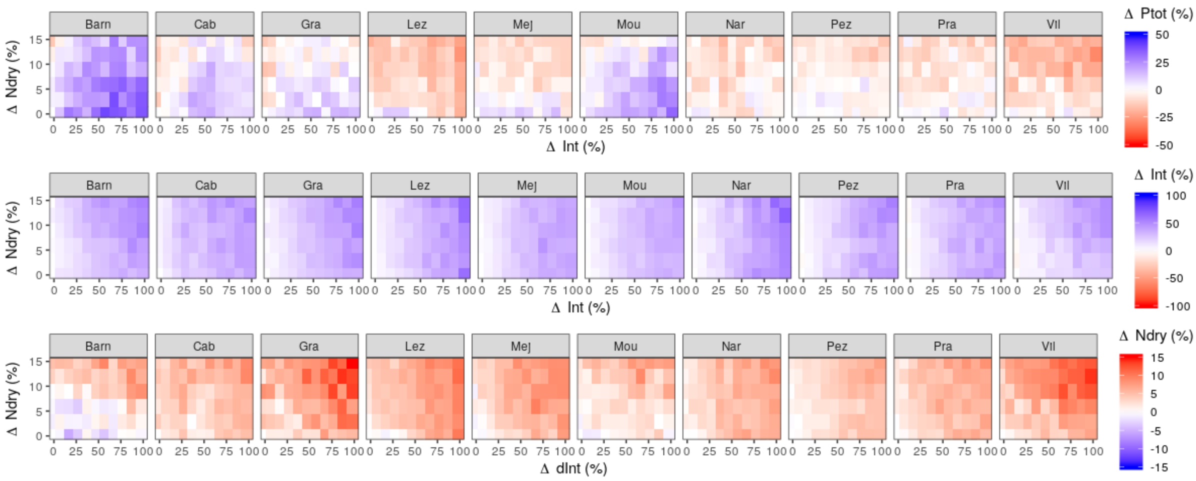

Fig 1: Change in annual precipitation (upper panel), daily rainfall intensity (middle panel), and annual number of dry days (lower panel) obtained after perturbating the rainfall statistics and recalibrating the rainfall generator.

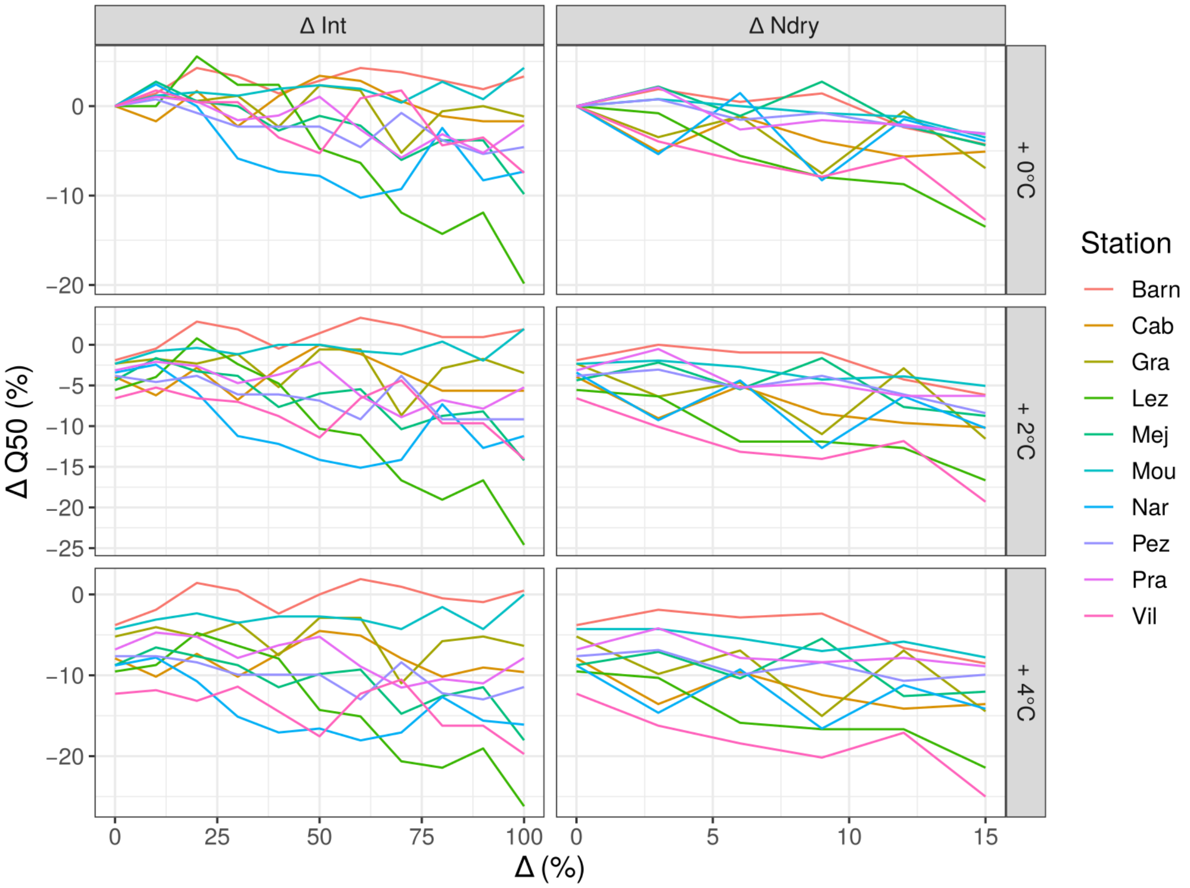

Fig 2: Sensitivity of the median of the simulated soil moisture to an increase of the mean daily rainfall intensity (left panel), and to an increase of mean number if dry days (right panel) under different temperature scenarios (+0 °C, +2 °C, +4 °C)

Consequently, since this approach is not satisfactory in our case, most probably due to the interdependence of different parameters in the Neyman-Scott model (as noted by the reviewer) that is probably amplified when conducting many re-calibration procedures, we kept the initial approach of perturbing the rainfall generator parameters.

But we added Figures 3 and 4 into the manuscript to show the relation between the perturbation of the parameters λ and ξ the change in the number of dry days and precipitation intensity of the generated rainfall series. Figure 3 shows that the perturbation of the parameter ξ is equivalent to perturbating the mean rainfall intensity. There is also a clear relation between the modified value of the λ parameter and the mean number of dry days. An increase of 100% of the λ parameter leads to an increase ranging between 10 and 18 % of the number of dry days depending on the station.

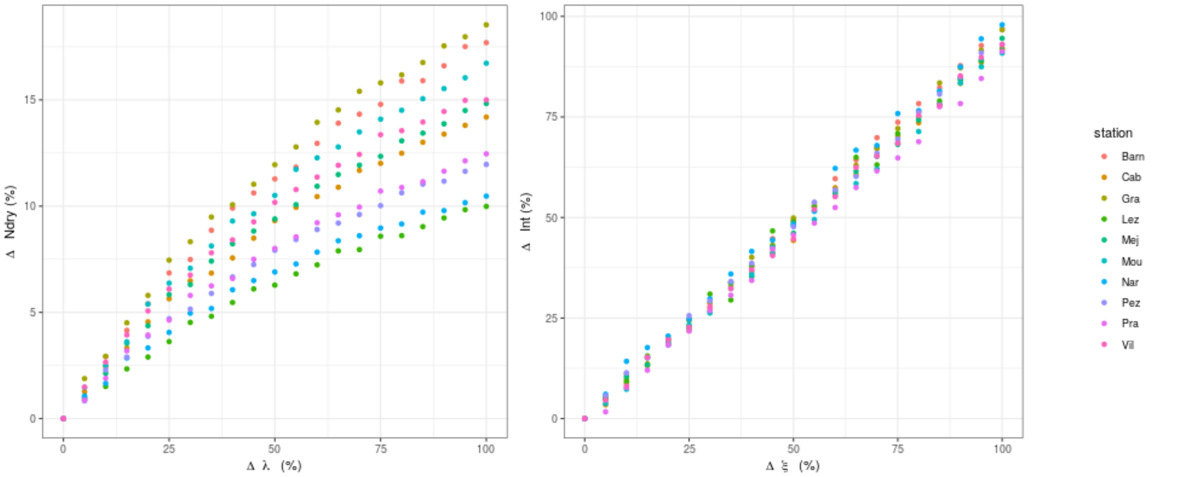

Figure 3: Change in the number of dry days (left panel) and rainfall intensity (right panel) when perturbing the λ and ξ parameters of the rainfall generator.

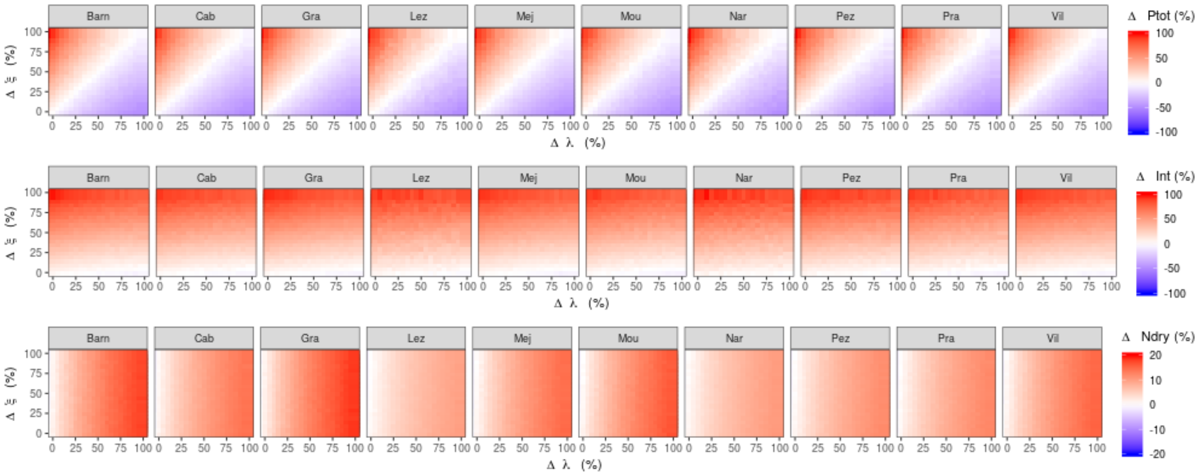

Figure 4: Change in the rainfall characteristics (upper panel: mean annual precipitation, middle panel: mean daily rainfall intensity, lower panel: mean number of dru days) of the generated rainfall time series when increasing the λ and ξ parameters from 0 to +100%.

In the initial manuscript we considered perturbations of the parameters up to +50%, which were equivalent to an increase up to 50% of the mean daily intensity and an increase up to 10% of the mean number of dry days. These values might be in fact too low to analyse the impact of extreme changes in rainfall patterns to soil moisture, that is why we extended the range of perturbation of the parameters up to +100%.

All the figures of the manuscript were updated in the revised manuscript. The general results and main conclusions remain the same as the ones in the submitted manuscript.

#2 Many parameter estimates seem to indicate a failure of the estimation method. For eta, the rain cell duration parameter, many zero

values appear (e.g. Pezenas, June to August) associated to very high values of xi and 1 for beta (the initial value of the optimization I guess). In Pezenas, in September, eta reaches the highest value of10 I guess, and lambda is very high (666.7). It affects maybe 10 months for all the stations, but the problem should be addressed. I cannot trust these simulations with these unrealistic parameter estimates. Possible solutions are: 1. Try different starting values for the optimization, 2. Change the objective functions (weighted sums, relative/absolute differences between observed and simulated statistics), 3. Smooth the estimation from one month to another, there is no strong reason to have a big difference between two consecutive months

We tried applying different starting values for the optimization, with a monthly variation to have a smoother variability between two consecutive months. Results show that the different calibration strategies we tested in order to modify the initial values for the calibration do not significantly reduce the unrealistic parameters values obtained and give very similar results in terms of rainfall intensities.

We kept in the revised manuscript the calibration results that yielded the most realistic values for the rainfall generator parameters. We also checked carefully the rainfall intensities generated to make sure we did not produce strongly biased values. The figure 5 below shows very similar rainfall intensities obtained with the different calibration strategies.

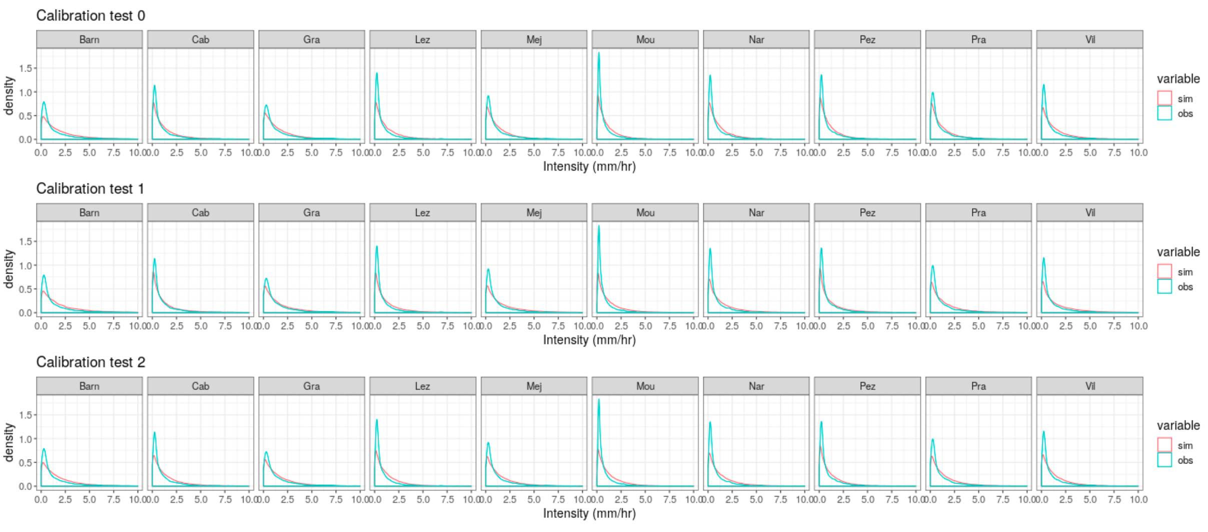

Figure 5: Density plot of observed (green) and simulated (red) hourly rainfall intensities

Minor comments:

p.2, l.14: Repetition of “soil moisture”, “For soil moisture” could be removed.

removed

p.2, l.32: For your information, a recent reference of scenario neutral approaches is “Keller, Luise, Ole Rössler, Olivia Martius, and Rolf Weingart-ner. 2019. “Comparison of Scenario-Neutral Approaches for Estimation of ClimateChange Impacts on Flood Characteristics.” Hydrological Processes 33 (4): 535–50.https://doi.org/10.1002/hyp.13341”.

we added this reference page 2, line 32

p.3, l.5: with -> and.

Replaced

Figure 1: Missing labels (Lon-gitude / Latitude).

Added

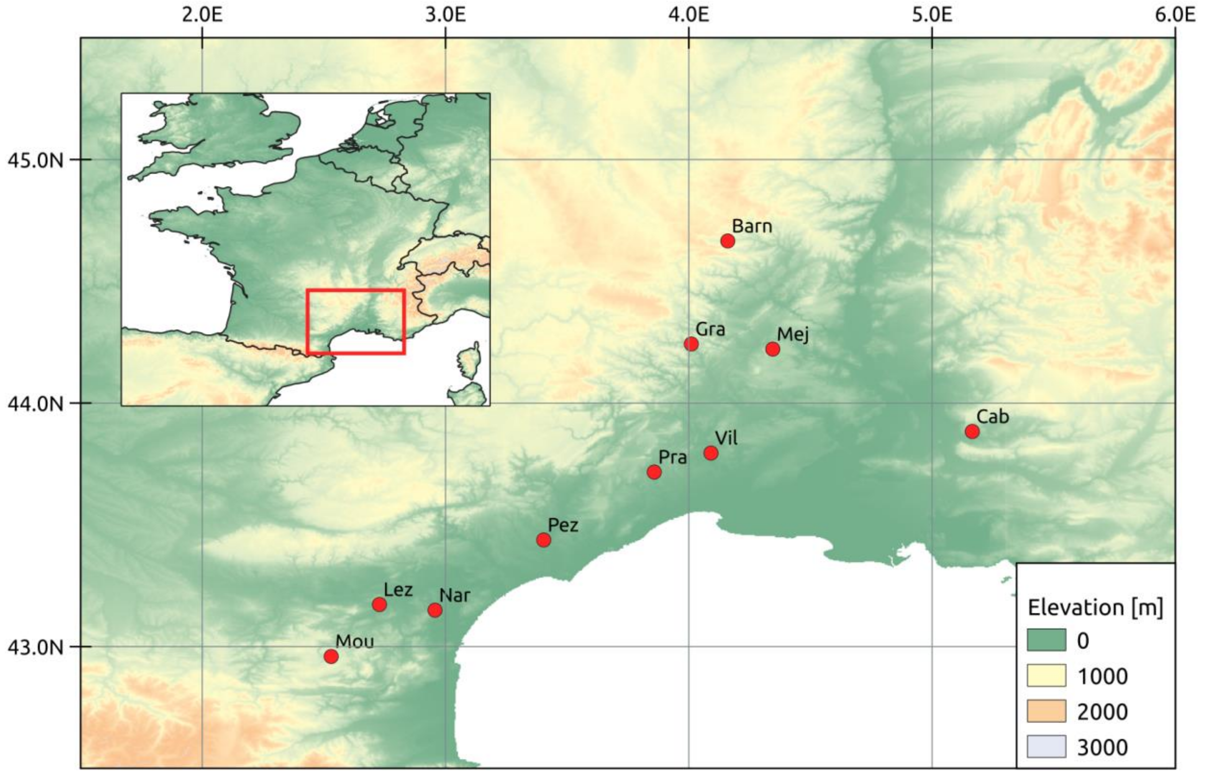

Figure 6: Localisation of the study sites in southern France

Figure 2: Please increase the font size.

Modified

p.7, l.3: “of” should be removed.

Removed

p.7, l.4-8: I think it would be fair to indicate that it is the standard version of the NSRP model, many more elaborate versions have been proposed in the last decades.

We added “the standard version of ..” ”

p.7: The mean number of raincell per storm is often denoted by the Greek letter nu, as is actually done in the manuscript in Section 3.4.1.

We replaced by Greek nu to be consistent with section 3.4.1.

p.8, l.1: I suggest indicating the statistical properties used for the estimation of the parameters. For these statistics at least, we should have a good agreement between the observations and the simulated values.

We added the rainfall properties:
“The statistical properties of rainfall included in the objective function to calibrate the model are: hourly mean, hourly variance, daily variance, lag1 autocorrelation of daily data, hourly skewness, daily skewness and the percentage of dry days.”

p.8, l.11: +4C the symbol “degree” is missing.

Added

p.10, l.4: there is a space after “+4” that should be removed.

Removed

p.10, l.11: There is a slight overestimation of the annual number of dry days for some stations (e.g. Barn), it could be noticed.

Added

p.12:m3.m-3 seems to be a strange unit (adimensional actually), is it correct

It is the standard unit for soil moisture measurements, so it is also the unit of the RMSE values computed.