Hydrology and Earth System Sciences Discussions

Hydrol. Earth Syst. Sci. Discuss., author comment AC1
https://doi.org/10.5194/hess-2021-548-AC1, 2022
© Author(s) 2022. This work is distributed under
the Creative Commons Attribution 4.0 License.

Reply on RC1

Camille Labrousse et al.

Author comment on "Declining water resources in response to global warming and changes in atmospheric circulation patterns over southern Mediterranean France" by Camille Labrousse et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-548-AC1, 2022

Dear Editor and referees

We are grateful for the valuable comments of referee 1 (in the following RC1) and we will make sure that these will be taken into account in the revised version of the manuscript. Please find below a detailed reply to the comments of RC1.

General Comments

Generally speaking, RC1 points a lack of clarity in the interests and objectives of the study. We apologize for this and we can ensure that these comments will be taken into account in the revised version of the manuscript.

In a previous study from Labrousse et al., (2020) which focused on past observations and trends analysis for the climatology in the same study area, the authors showed a more pronounced warming trend in the Herault and Orb watersheds (and also, although slightly reduced, in the Tech watershed) compared to the Aude, Agly and Tet watersheds. Synchronously, the evolution of annual precipitation depicted a slight decrease in these latter watersheds whereas no changes were found in the former ones. Seasonality of precipitation is also known to be different among the watersheds. Seasonal variability is lowest in the Aude and upper Agly, Tech and Tet watersheds, and strongest in the entire Herault and Orb watersheds (Lespinas et al., 2010).

Given this background, in our current study, a **first objective** was to statistically test the differences in the climatological behaviour of the study area. We expected two clusters beforehand, corresponding more or less to the two groups of watersheds describes above, but which were not necessarily exactly delineated by the watershed contours. This has been investigated through the implementation of a K-means clustering, following the results in the study of Manzano et al. 2019 over Spain. This analysis confirmed our *a priori* hypothesis as it separates a eastern cluster which dominantly includes the Herault, Orb and Tech watersheds, and a western cluster which dominantly includes the Aude, Agly and Tet watersheds. Future trends, shown in Figure 6 of our study, also confirmed the different behaviour of both clusters in the future GCM/ RCM simulations: a stronger decrease in the annual precipitation is depicted for the Aude, Agly and Tet watersheds (e.g. the western cluster) compared to the other watersheds (e.g. the eastern cluster). In a **second objective**, statistical relationships between the hydro-climatic parameters for

each cluster and teleconnection indices gave more understanding about the reason of the different behaviours observed. In the western cluster, precipitation and water discharge were more closely related to Atlantic indices, whereas precipitation and water discharge in the eastern cluster were more associated with Mediterranean indices. One interesting detail shown in Figure 3 is the strong anti-correlation for fall and winter precipitation in the eastern cluster with the Mediterranean indices (e.g. WeMO and MO). For the Mediterranean, fall and winter precipitation represent a large part of the total annual precipitation. Thus, one can expect that a change in the Mediterranean indices can have an important impact on the precipitation occurring in the eastern cluster. Teleconnection pattern are indeed powerful indicators in order to study shifts in the evolution of climate. Regional and Global Climate Models (RCMs and GCMs respectively) reproduce these patterns but they can suffer from a coarse spatial resolutions and previous studies already pointed out the lack of accuracy in the reproduction of local scale systems especially for precipitation (see for example (Giorgi et al., 2016; Quintana-Seguí et al., 2011; López-Moreno et al., 2008). Therefore a **third and final objective** of our study is to show that GCMs can capture with reasonable accuracy the Atlantic teleconnections indices, but fail to reproduce the Mediterranean ones (this is shown in Figure 4 and especially in the boxplot of Figure 4a), which consequently also affects their ability to predict water cycle changes. The question of the reliability of climate model predictions is important to address and especially for the Mediterranean area where more frequent and intense extreme events are expected in the future.

In shorter words, our study does not only intend to produce future trends of climatic variables and water resources. It principally demonstrates that the quality of GCM/ RCM simulations depends on the climate regimes which, as this is the case for the Mediterranean climate type, might rely on small scale patterns which are probably more difficult to be reproduced in these models. Of course, the purpose of our study is not to evaluate the quality of climate scenarios from a modelling prospective, but combining observations from the past with future simulations can be helpful in order to evaluate the reliability of these scenarios and to gather information for further improvement during subsequent studies.

1 Introduction

RC1 states that the morphological effects in the study area are not well investigated. Morphological settings in the study are known to have a strong influence on the average climatology (Lespinas et al., 2014, 2010). Indeed the extension of the study area is about 12000 km^2 in which almost 32 % of the land is equal or above 500 m of elevation. Those high lands include the mountains of the Pyrenees in the South and the High Plateau of the Languedoc in the North. The upper part of the watersheds of the Tet, Tech and Aude rivers are located in the Pyrenees whereas important portions of the Herault and Orb watersheds are located in the High Plateaus of the Languedoc. A large valley which is oriented in the West – East direction separates both high areas and it represents a large part of the Aude watershed. In this study we show that the air masses coming from the Atlantic (which is located further West) are capable of penetrating the study area through the valley of the Aude watershed and have consequently an effect on the overall climatic functioning of part of the study area. In fact, average climatology of the watersheds shows a weaker seasonality of precipitation for the Aude watershed compare to the Herault and Orb watersheds which show the strongest seasonality (in average over the period 1959-2018 10 % of the total amount of annual precipitation occur in the wettest month for the Aude watershed against 15 % for the Herault and Orb watersheds). The Herault and Orb watersheds are more closely influences by air masses of Mediterranean origins. The High Plateau of the Languedoc which makes their northern and northwestern limits represents an orographic barrier that block air moisture from the sea during the fall season and enhance heavy rainfall events.

2 Material Methods

Water discharge of each cluster is the sum of the water discharge for each river whose delineations of the watershed fall within the limits of a cluster. Water discharge data are retrieved from gauging stations located downstream of the rivers and close to the outlet. Data are available in $m^3.s^{-1}$ which we convert per unit area and per year, being thus $mm.year^{-1}$. Water discharge for the western cluster suffer then from an approximation since part of the watersheds belonging to it actually falls in the eastern cluster. Despite this, Figure 3 and the correlation analysis with the teleconnection indices are able to show the same pattern between the water discharge series and the precipitations series with the teleconnection indices. However, weaker significances are depicted for the connection between the water discharge and the Mediterranean indices, which is potentially a consequence of the underlying inaccuracy.

2.3 K-means clustering

Line 115 about the initial conditions for the K-means clustering examination. The number of clusters and type of the variable analysed were the 2 factors considered to set the initial conditions. The former was based on our *a priori* assumption (see above) that at least 2 zones were climatically distinct. Of course, in the experimental phase of our work, we also tested the separation of our study zone in more than 2 clusters. A 3rd zone which would separate the watersheds located on the foothills of the Pyrenees could also be pertinent. However, the subsequent analysis of correlations between the teleconnection indices and the climatology of each clusters stressed us to choose a minimum number of clusters. Because the study area is small and discriminate the resulting clusters based on their connections with teleconnection indices would be less clear. The type of variable also matters. We ran the K-means test over historical monthly series of temperatures, precipitation and RDI-03. The two first variables separated the area according to the elevation, since temperatures are colder in elevated areas and precipitation more abundant. However, the RDI-03 is a standardized variable which makes it comparable in the spatial scale and therefore it is the best suited variable for this analysis.

Line 123 : the « see below » is a proofreading failure.

2.5 Wavelet analysis

The wavelet transform is a type of mathematical transform that represents a signal according to translated and dilated versions of a finite wave. Compared to a Fourier transform which transforms a time series from its time domain to its frequency domain, the wavelet transform decomposes a signal into a series of wavelets localized both in space and time scales. This type of method provides an efficient approach for the analysis of non-stationary variables such as hydrological and atmospheric time series (e.g., Conte et al., 2021; Sang, 2013; Kang and Lin, 2007). The term « Morlet wavelet » is simply the kind of wavelet we applied. Beforehand, the time-series is compared to a Morlet wavelet transform. The term « cross-wavelet » refers to the analysis of two wavelet transforms from two different time-series together. This one exposes the strength of the common power between the two wavelet spectra as well as the relative phase called coherence of the two wavelet spectra in the time-frequency scale. It can therefore be considered as a correlation coefficient between the two time series.

Table 2 : This is a proofreading omission, the 6th RCM will be added in the revised version of the manuscript

3 Results

Line 210 : By « more complex » we mean that the Mediterranean functioning is more

irregular than on the Atlantic side. Therefore relationships with water discharge show less long cycles and weaker relationships, as shown also in the correlation analysis. In fact the wavelet analysis here confirms the findings through the K-means since it can show that the eastern cluster has a more irregular behaviour than the western cluster.

Figure 4 : it seems that axis are not missing. Did you maybe mean that it is not enough noticeable ?

Line 282 : Figure 4 compares series of the teleconnection indices with the ones reproduced from GCMs data. In the boxplot (Figure 4a) we see that GCMs could not statistically reproduce the WeMO, and failed also to reproduce with accuracy the variability of MO (the observed box –in white- is much shorter and the boxes for each GCMs). This is also highlighted in Figure 4 b where the observed historical series (blue curve) of WeMO decreases strongly while the series for each GCMs (grey curves) stay still. For MO, as in the boxplot, the observed series has less variability than the ones computed from the GCMs.

Afterwards, with future computation of each teleconnection indices, we found a decrease in the values of WeMO and Scand.

4 Discussion

We will take into account the comment about making sub-sections to bring more clarification in this part of the manuscript.

Table 4 about REMO 2009 : This is the name of the missing RCM of Table 2 (requested in a previous comment by RC1). It will be added in a revised version of the manuscript.

Conclusions

Future simulations of climatic and hydrological variables are in fact not the centre of interest of our study. What we show is that climate is strongly related to large scale atmospheric circulation which can be studied via teleconnection patterns. Our study area is divided into two major zones which behave differently and therefore have distinct relationships with the overall atmospheric circulation. Thus, for future simulations, an accurate reproduction of the atmospheric circulation by GCMs models is important for the reliability of the climatic evolution. But in our case, for the eastern cluster which is obviously more closely connected to air masses from Mediterranean origins, GCMs failed in reproducing the teleconnection indices over the Mediterranean in the past. This also suggests that for the future projections, simulations could suffer from enhanced uncertainties. This is important since the Mediterranean climate is more vulnerable to extreme events and additional efforts might be necessary to quantify the evolution of those extremes in the future.

References

Conte, M., Contini, D., and Held, A.: Multiresolution decomposition and wavelet analysis of urban aerosol fluxes in Italy and Austria, Atmospheric Research, 248, 105267, https://doi.org/10.1016/j.atmosres.2020.105267, 2021.

Giorgi, F., Torma, C., Coppola, E., Ban, N., Schär, C., and Somot, S.: Enhanced summer convective rainfall at Alpine high elevations in response to climate warming, Nature Geosci, 9, 584–589, https://doi.org/10.1038/ngeo2761, 2016.

Kang, S. and Lin, H.: Wavelet analysis of hydrological and water quality signals in an agricultural watershed, Journal of Hydrology, 338, 1–14,

https://doi.org/10.1016/j.jhydrol.2007.01.047, 2007.

Labrousse, C., Ludwig, W., Pinel, S., Sadaoui, M., and Lacquement, G.: Unravelling Climate and Anthropogenic Forcings on the Evolution of Surface Water Resources in Southern France, 12, 3581, https://doi.org/10.3390/w12123581, 2020.

Lespinas, F., Ludwig, W., and Heussner, S.: Impact of recent climate change on the hydrology of coastal Mediterranean rivers in Southern France, Climatic Change, 99, 425–456, https://doi.org/10.1007/s10584-009-9668-1, 2010.

Lespinas, F., Ludwig, W., and Heussner, S.: Hydrological and climatic uncertainties associated with modeling the impact of climate change on water resources of small Mediterranean coastal rivers, Journal of Hydrology, 511, 403–422, https://doi.org/10.1016/j.jhydrol.2014.01.033, 2014.

López-Moreno, J. I., Goyette, S., and Beniston, M.: Climate change prediction over complex areas: spatial variability of uncertainties and predictions over the Pyrenees from a set of regional climate models, 28, 1535–1550, https://doi.org/10.1002/joc.1645, 2008.

Quintana-Seguí, P., Habets, F., and Martin, E.: Comparison of past and future Mediterranean high and low extremes of precipitation and river flow projected using different statistical downscaling methods, 11, 1411–1432, https://doi.org/10.5194/nhess-11-1411-2011, 2011.

Sang, Y.-F.: A review on the applications of wavelet transform in hydrology time series analysis, Atmospheric Research, 122, 8–15, https://doi.org/10.1016/j.atmosres.2012.11.003, 2013.