Review of Camila Alvarez-Garreton et al. “Progressive water deficits during multi-year droughts in central-south Chile”

- by Anne Van Loon

This paper uses a recently published dataset to look at changes in rainfall-runoff relationships during multi-year drought covering a range of different conditions in Chile. The authors conclude that both groundwater and snow play an important role and that some regions are more affected by prolonged drought and others by short extreme drought. The topic of the paper is important and the range of catchments included in the dataset provides interesting insights. The analysis is done well and the paper is generally well-written. The paper can be suitable for publication in HESS after a number of (relatively minor) revisions. Below I provide my suggestions for improvement of the paper.

General comments

The authors do not mention potential human influence in the catchments (except in the final sentence of the manuscript, l.461). It is unclear whether these catchments are completely without any human influence on the hydrology (which I doubt because they are quite large and cover a large part of Chile, so they are unlikely not to include reservoirs, forestry plantations, agriculture). There might for example be an increase of abstraction or change of land use during multi-year drought that might influence the rainfall-runoff relationship. CAMELS-CL includes information on land use, intervention degree, water rights and it would be greatly improve the paper if this was included in the analysis. If this cannot be included in the current paper, the authors must at least mention the degree of human influence in the catchments at the start of the paper and discuss potential effects of human influences on the results at the end (in the Discussion section).

The authors should be more specific about the role of snow vs. groundwater when they talk about memory (for example in the abstract l.16-18). This starts with the classification of catchments in semi-arid vs. temperate catchments, which seems to be partly overlapping with snow-dominated vs. rainfall-dominated catchments but this is not clearly identified. For example, on p.5 l.111-113 the authors state that in central Chile there is an Mediterranean regime, whereas in snow-dominated basins “streamflow peaks in spring / early summer”, which makes me think that the snow-dominated basins are located in southern Chile. But then the classification (l.113-118) seems to be only based on precipitation and not on snow and Fig.1 shows that there is more snow in the north. Also, an additional classification of catchments is introduced on p.7 l.183-185, where snow-dominated catchments are defined as having a snow fraction larger than 0.3. On the other hand, the authors assessed groundwater by the BFI in a continuous way, so without a classification between groundwater-dominated and not groundwater-dominated catchments. I would suggest to do the same for both snow and groundwater, so either a continuous or a binary classification. Related to this, I think the authors can do a bit more to clarify the role of groundwater. On p.13 l.287-291, they state that soil properties and geology are important, but that these characteristics are commonly not available. However, the CAMELS-CL dataset does include information on these variables (and BFI) and I strongly encourage the authors to include this in their analysis. How does the BFI based on modelled data relate to the BFI and soil and geological variables of CAMELS-CL? The difference between snow and groundwater storage should also be discussed more clearly in the Discussion section. On p.17 l.368-370, the authors now mention both groundwater and snow, but it is unclear to which catchments they are referring and whether both types of storages might occur in the same catchment. This is important when they draw conclusions about the drivers for changes in RR relationships (for example on p.18 l.393-398), because the drivers are interrelated, like

they also mention in the Conclusion (l.426-429). So, in a revised manuscript I would like to see a clearer discussion of the role of these two drivers and their interrelations.

There is some unclarity about the period of the megadrought period investigated. Multiple years are mentioned, especially for the end year (2018/19/now). It is important to clarify this. It is currently for example, not clear which period your 8-yr average refers to. If you used data from 2010 to 2018, then this is a 9-year period. Different years / periods are also mentioned on, for example, l.11, 55, 128-129, 143, 150, 339, 417, 421. And in Fig.8 the MD seems to be 2007-2018. Please clarify the time period of the MD itself and which period of record you used for the analysis of the MD (I understand that these can be different).

The Discussion section needs to include a paragraph on the uncertainties in the HBV model and the classification decisions and how both of these could have influenced the results. As mentioned before, also a paragraph on anthropogenic influences should be added. I also suggest the authors to relate their work to that of Stoelzle et al. (2014).

I don't fully agree with the conceptualization of Carey et al. (2010) that catchments with lower storage are more resilient. You could argue that the opposite is true and those catchments are less resilient because they dry up immediately. Maybe the authors can add their view on this.

Specific comments

l.115-118: Please clarify how the distribution between semi-arid catchments was chosen. Was this based on literature, a random split, or an iterative analysis? Would your discussion of the results have been different if you would have chosen this split differently?

l.157: Please clarify how the two boxes were configured in HBV: in parallel or consecutive, and explain what the boxes represent and why this matches the situation in the catchments.

l.164-167: I'm not convinced that HBV can correctly distinguish between soil and groundwater storage if it does not represent groundwater correctly (as explained by the authors due to the lack of drainage when streamflow ceases and because there is no surface runoff in the model so all precipitation excess and snow melt move through the soil and groundwater boxes).

l.185: Why is 0.3 chosen to classify snow-dominated catchments? From literature? Have you done a sensitivity analysis on this number?

l.187: I'm assuming that you used modelled streamflow to calculate BFI?

l.279: High model efficiencies are not a surprise in snow-dominated catchments with a clear seasonal regime. Please discuss this.

Fig.7: It would be interesting to explore a bit more the catchments that deviate from the pattern, for example the ones north of 36 degrees that have lower correlations then their neighboring catchments. Would this be related to effects of groundwater or anthropogenic influences? Please explore.

l.349-351: Here you mention ET as an important factor. This is an important point that could be highlighted more, especially since ET during the recent MD is probably larger than during earlier 8-yr periods because of climate change. This should be discussed more in the Discussion section. I was also

wondering why you see the effect of ET only in the temperate catchments and not in the semi-arid ones? These would correspond more to the Australian catchments Saft used in her analysis.

l.358-362: Fig.9 needs more explanation in the text. The results presented in Fig.9 are now only mentioned in the Discussion section (l.399-404). This should be moved to the Results section. Also, how have the three cases been defined, per catchment or overall? I'm wondering whether the drought/wet years are actually the same in central and south Chile.

l.435-436: These catchments also have less ET.

Technical corrections

Would the title not be better as "during a multi-year drought" (singular) as the plural suggests that multiple drought periods like the MD were analysed.

I would suggest to check the English throughout the manuscript. There are quite a lot of issues with prepositions, for example on l.113-117, 174, 193, 234, 237, 325.

l.24: dependant > dependent

l.20-23: add latitudes to central and southern Chile so that the abstract is understandable on a standalone basis. Also, when you talk about snow-dominated or semi-arid regions, please add where they are located.

l.43: why "potential" drought propagation?

l.56: what do you mean with "global changes"?

l.108: "less than 100 mm **in** the north"

l. 129: "we compared them…" > what do you mean with "them"? Do you mean a value for each catchment?

l.143: 1018 > 2018

l.163: simulated > simulate

l.181: remove "then"

l.195 & 338-339: catchments memory > catchment memory

l.200: 1979-**2018**

l.201: **are** evident

Fig.2: the non-linear y-axis is confusing. You mention in the caption that each line is a catchment, but it would be helpful to indicate this on the figure axis as well.

l.223: what do you mean with "up to 90% of streamflow deficits"? Do the extremely dry years have streamflow deficits up to 90% or do 90% of streamflow deficits classify as extremely dry? Explain more clearly in the Methods section how you have calculated the deficit in % (% of what?).

Fig.3: So the boxplots exclude the MD, so only cover the period 1979-2009? Please add this in the caption.

l.233: “presenting **8-year** mean runoff”

l.246: “negative shift; that is, …”

l.278-279: “values of 0.72, …” > values of what? Nash-Sutcliffe model efficiency?

Fig.7: Are bar-plots the best way to visualize this? I’m assuming that the blue-grey bars are when the blue ones are below the grey, but what about the green bars then? Why not just use points?

l.319: should “from the previous year” be moved forwards to after “the precipitation”? Precipitation does not influence previous year streamflow, does it?

l.330: “the difference between runoff and precipitation deficits” on a yearly basis?

Fig.8: how have dry years been defined?

l.361: persistent > multiple (two and more)?

Fig.9: Panel a > a) and b), panel b > c) & d)

l.403: result > results

l.449: dependant > dependent

l.453: catchments response > catchment response

References:

Carey, S. K., Tetzlaff, D., Seibert, J., Soulsby, C., Buttle, J., Laudon, H., McDonnell, J., McGuire, K., Caissie, D., Shanley, J., Kennedy, M., Devito, K. and Pomeroy, J. W.: Inter-comparison of hydro-climatic regimes across northern catchments: Synchronicity, resistance and resilience, Hydrol. Process., 24(24), 3591–3602, doi:10.1002/hyp.7880, 2010.

Stoelzle, M., Stahl, K., Morhard, A., and Weiler, M. (2014), Streamflow sensitivity to drought scenarios in catchments with different geology, *Geophys. Res. Lett.*, 41, 6174– 6183, doi:10.1002/2014GL061344.